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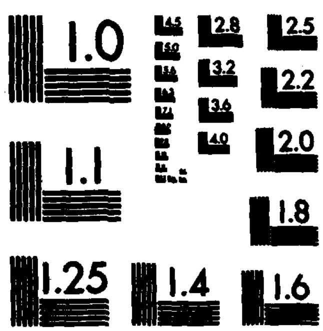

MICROCOPY RESOLUTION TEST CHART

(4)

DOT/FAA/RD-82/90

Program Engineering &
Maintenance Service
Washington, D.C. 20591

AD-A146 435

In-Service Evaluation of the Dalmo Victor Active Beacon Collision Avoidance System (BCAS/TCAS)

T.P. Berry
R.D. Brock

October 1982

Final Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
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NOTICE

Technical Report Documentation Page

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16. Abstract

This report details the installation of the Dalmo Victor Collision Avoidance System aboard two Piedmont Airlines B-727 aircraft and the performance of the System during 928 hours of operational flights. During this period, 32 resolution advisories and 329 traffic advisories were recorded. A large percentage of these advisories were caused by other aircraft that were on the ground. A technique to eliminate on-ground aircraft advisories was developed but not tested.

FAA and airline personnel observed approximately one-third of the data collection period and provided comments on system usefulness. Appendixes to the report give data as recorded during the resolution advisories.

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METRIC CONVERSION FACTORS

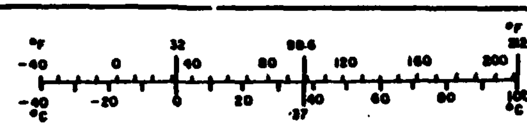
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FOREWORD

Under Contract DTFA01-80-C-10093, ARINC Research Corporation collected and analyzed data on the operational performance of a collision avoidance system that had been developed by Dalmo Victor Operations of Bell Aerospace Textron. Through a subcontract, Piedmont Airlines installed the collision avoidance system in two of its B-727 aircraft. The systems provided more than 900 flight hours of performance data over a four-month period. This report describes the experiment and the results obtained.

ACKNOWLEDGEMENTS

This project would have been much more difficult without the enthusiastic cooperation and support of the people of Piedmont Airlines. Without exception, every Piedmont employee gave the same friendly, cheerful, and timely help that is the hallmark of the Airline.

Hundreds of Piedmont people were involved in this project: maintenance personnel, flight crews, scheduling, public relations, flight operations, and executive office personnel. From these many people, we wish to especially recognize Captain Fred Womack, Mr. Al Lenderman, Mr. Kermit Oakley, Mr. Phil Peacock, and Mr. Dave Kepple.

SUMMARY

On 4 November 1981 the first of two developmental models of a Traffic Alert and Collision Avoidance System (TCAS) was approved by the FAA Southern Region for operation aboard Piedmont Airlines Boeing 727 aircraft during normal passenger-carrying operations. This approval was in the form of a supplemental type certificate issued with the restriction that the system was to be used for collection of data on the operational performance of the TCAS and not to be used by the flight crews.

Over the following five months data were collected on the operational performance of the TCAS during 928 hours of flight time. The data were generated from two sources: (1) a data recording system aboard the test aircraft that recorded quantitative data generated by the TCAS each time the system detected a potential conflict and activated the system displays, and (2) qualitative comments on the system performance and utility of TCAS, prepared by cockpit observers who were skilled in jet transport operations.

This report describes the project planning, system installation and certification, data collection method and data analysis techniques, results of the data analysis, and conclusions reached as a result of the evaluation. This summary will deal primarily with the results and conclusions of the project.

The system tested was developed by Dalmo Victor Operations of Bell Aerospace Textron under contract to the Federal Aviation Administration. It consisted of a processor unit installed in the aircraft electronics compartment, two antennas mounted on the top and bottom of the aircraft, a control/display unit located in the flight observer area of the cockpit outside the view of the flight crew, and an instantaneous vertical speed indicator, modified to display aircraft maneuver advisories, mounted atop the control/display unit. In addition, a time-of-day clock and digital tape recorder were installed in the electronic compartment of the aircraft. The last two items were used as test instrumentation and would not be part of an operational system.

The quantitative evaluation of the TCAS performance discussed in this report is primarily based on digital data recorded in flight by test instrumentation furnished as part of the TCAS avionics. During the evalua-

tion and analysis, a number of anomalies were found in the recorded data. The majority of these anomalies were caused by the design and operation of the data recording system, some represented TCAS equipment failures, and at least one anomaly was caused by an installation problem that was corrected in the initial days of the program.

Almost all the anomalous data were purged from this report during the analysis process. Even so, there may be some remaining anomalous data that are not fully understood at this time. Since the objective of this evaluation was the examination of the operational aspects of TCAS, investigation of the technical performance of the system was beyond the scope of the project. Because of the unique source of the technical data developed during this evaluation, the data have been furnished to the MITRE Corporation, MIT Lincoln Laboratory, and Dalmo Victor Operations for additional examination of the technical performance of the TCAS. This further examination of the technical performance of TCAS will doubtless yield valuable information for those organizations. However the examinations are not expected to make any substantial change to this report on operational performance. Collectively, this report and the additional technical performance analysis should substantially increase confidence in the performance of the next generation of TCAS.

The Dalmo Victor system implemented the collision avoidance logic developed for the FAA by MITRE Corporation. That logic examines the range, range rate, altitude, and altitude closure rate to identify a conflict situation. When a conflict is recognized, the logic develops a vertical escape maneuver to resolve the conflict. The system has no capability for computing horizontal escape maneuvers.

The aircraft flew normal routes and were indistinguishable from other Piedmont B-727 to air traffic controllers who handled the flights. The aircraft were not locked into any specfic routing and at some time flew every segment of the Piedmont B-727 route structure.

The first flight with TCAS aboard was made on 4 November 1981, but the majority of the data were recorded during January, February, and March of 1982. Cockpit observers were aboard during approximately one-third of the data collecting flights.

During the 928 hours logged, the system generated 329 traffic advisories and 32 resolution advisories. These events occurred during normal airline operations and did not represent ATC system errors. Forty-five percent of the traffic advisories (148) and 22 percent of the resolution advisories (7) were generated by aircraft on the ground at the time of the event. A technique to suppress advisories related to aircraft on the ground was recommended early in the evaluation, but the desensitization technique could not be implemented in the test systems while the test was under way.

Traffic advisories on airborne aircraft averaged one each 5.13 flight hours. Resolution advisories on airborne aircraft averaged one each 37.15 hours. The majority of the observed traffic advisories on airborne aircraft (29 of 50) were caused by other air carrier aircraft. In 16 cases (32 percent) the observers were unable to determine the type of the other aircraft. Only 3 (6 percent of the 50 traffic advisories were identified as being related to general aviation type aircraft. The remaining two incidents were caused by a helicopter and a commuter aircraft.

Half of the observed resolution advisories regarding airborne aircraft (4 of 8) were caused by general aviation aircraft. Most of those conflicts occurred near an airport with both aircraft operating in visual meterological conditions (VMC), with visual contact, and under control of the appropriate ATC facility.

Most traffic advisories and resolution advisories involving airborne aircraft occurred below 10,000 feet mean sea level (MSL). In 62 percent of the incidents, the other aircraft was more than 500 feet and less than 1500 feet above or below the test aircraft at the time the advisory was started. Only 21 percent of the advisories were started with less than 500 feet vertical separation between the two aircraft. Five hundred feet is the minimum vertical separation for opposite-direction aircraft operating in VMC. Most of the advisories (81 percent) were caused by aircraft forward ($\pm 90^\circ$ relative bearing) of the TCAS aircraft at the time of advisory. There were no recorded cases in which an advisory was caused by another aircraft overtaking the test aircraft.

No vertical speed minimum (VSM) advisories were recorded as the first advisory selected by the TCAS. Seventy-five percent of the initial resolution advisories related to airborne aircraft were vertical speed limits (VSLs) or negative advisories. Only 6 of 25 advisories (24 percent) were positive advisories.

Of more interest is the frequency of corrective advisories, that is, those requiring an alteration in flight path. Eight of the resolution advisories would have required deviation from the recorded flight path, while 10 others might have required some change in flight path, depending on the vertical rate of the TCAS aircraft at the time of the advisory. For example, if a "DO NOT CLIMB" advisory was displayed at a time when the climb rate was decreasing in response to pilot initiation of a level-off, there would be no requirement for the TCAS aircraft to deviate from its planned flight path.

A corrective advisory is a resolution advisory that instructs a deviation from current vertical rate, as for example a "DON'T CLIMB" when the aircraft is climbing. A preventive advisory is a resolution advisory that further instructs the pilot to avoid certain deviations from current vertical rate, as for example a "DON'T CLIMB" when the aircraft is level.

Fourteen of the resolution advisories were preventive, i.e., they did not require deviation from the current flight path, but did advise against initiation of certain vertical maneuvers.

The data recorded during this evaluation indicate that an average air carrier flight might expect to see one corrective TCAS advisory per month.

The average resolution advisory sequence observed during the evaluation consisted of approximately 14 seconds of precursor traffic advisory, 10 seconds of resolution advisory, and 26 seconds of post-resolution advisory traffic information. Those are statistical averages and vary considerably from incident to incident. They are based on data collected with no response by the TCAS aircraft crew and will change when the crew initiates response action to resolution advisories.

The cockpit observers believed that improvements to the desensitization scheme were required to eliminate advisories related to aircraft that were on the grund. With that exception, they believed that the TCAS performed its task with no other unacceptable effect on flight operations. The cockpit observers were not unanimous in their endorsement of proximity information. Some believed that resolution advisories were sufficient to enable the flight crew to respond to a potential collision. Some observers believed that traffic advisories were so necessary to the collision avoidance task that they should be an integral part of the system. The majority of the observers believed that traffic position information provided desirable information to the flight crew that would be used in evaluating the conflict situation and moderating the response maneuver.

This evaluation shows that the TCAS functions as expected in an operational airline environment. The major shortcoming with the current system was the high incidence of advisories generated in response to aircraft on the ground, a problem for which a solution has been indentified but not tested. The comments of the observers indicate that advisory rates regarding airborne aircraft appear to be well within the acceptable range. The TCAS appears sufficiently mature to enter a phase that involves the interaction of the flight crew during routine air carrier operation.

CONTENTS

CONTENTS (contd.)

CHAPTER ONE

INTRODUCTION

1.0 PROJECT OVERVIEW

The Federal Aviation Administration (FAA) is developing the Traffic Alert and Collision Avoidance System (TCAS) to reduce the risk of mid-air collisions. The TCAS development program includes development of detection and resolution algorithms, development and testing of hardware, and development and validation of flight crew procedures for use of the TCAS. This report presents the results of an evaluation of a developmental TCAS installed aboard commercial airline aircraft operating in normal, scheduled airline service.

The quantitative evaluation of the TCAS performance discussed in this report is based primarily on digital data recorded in flight by test instrument furnished as part of the TCAS avionics. During the evaluation and analysis, a number of anomalies were found in the recorded data. The majority of anomalies were caused by the design and operation of the data recording system, some represented TCAS equipment failures, and at least one was caused by an installation problem that was corrected in the initial days of the program.

Almost all the anomalous data were purged from this report during the analysis process. Even so, there may be some remaining anomalous data that are not fully understood at this time. Since the objective of this evaluation was the examination of the operational aspects of TCAS, investigation of the technical performance of the system was beyond the scope of the project. Because of the unique source of the technical data developed during this evaluation, the data have been furnished to the MITRE Corporation, MIT Lincoln Laboratory, and Dalmo Victor Operations for additional examination of the technical performance of the TCAS. This further examination of the technical performance of TCAS will doubtless yield valuable information for those organizations. However, the examinations are not expected to make any substantial change to this report on the operational performance. Collectively, this report and the additional technical performance analysis should substantially increase confidence in the performance of the next generation of TCAS.

Two Boeing 727 airplanes, owned and operated by Piedmont Airlines, were each equipped with a set of TCAS electronics, test instrumentation,

and recording equipment manufactured under FAA contract by Dalmo Victor Operations of Bell Aerospace Textron. The equipment installation was designed by Piedmont Airlines, and a Supplemental Type Certificate (STC) was issued by the FAA Southern Region. The system display was located outside the view of the normal flight crew, but within view of persons occupying the cockpit observer seats.

Two types of data were collected. Automatic recordings were made of system parameters each time a conflict arose. The recorded data included test aircraft status information, information on each aircraft being tracked by the collision avoidance system at the time, and information on the relationship between the test aircraft and the other aircraft. The test observers completed a questionnaire form and prepared an audio recording for each potential conflict. These records provided a subjective evaluation of the conflict incident, including information on the circumstances that brought about the conflict and how it was resolved.

ARINC Research Corporation developed the test concept, prepared the test plan, selected and trained the observers, supervised the data collection, analyzed the data, and prepared this report. Piedmont Airlines, working as a subcontractor, developed the equipment installation design, installed the avionics, made application for the STC, and flew the system.

1.2 OBJECTIVES

The primary objective of this operational flight evaluation is to assess the operation of the TCAS in an air carrier operational environment and to develop an understanding of the potential effect of alerts on air carrier flight operations, flight crews, and ATC controllers and of the frequency of alerts and circumstances under which they occur.

The system installed in the test aircraft provided the same type of service to the test observers that will be available to flight crews using the TCAS II. The system provided the same type of information found essential in earlier simulation studies* under contract DTFA01-C-79-4091, and the observer pilots provided further confirmation of the results developed under that contractual study.

1.3 REPORT ORGANIZATION

This report is organized into seven chapters and four appendixes. Chapter Two describes the experimental approach used in conducting this test. Chapter Three describes the equipment installation in the test aircraft. Chapter Four describes the data collection method. Chapter Five presents the data analysis results. Chapter Six presents some representive conflict events. Chapter Seven contains the conclusions drawn from the analysis.

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*An Evaluation of Aircraft Separation Assurance Concepts Using Airline Flight Simulators, November 1979, ARINC Research Corporation Publication 1343-01-3-2058.

The following appendixes are attached to the report:

- Appendix A - Observer Instructions
- Appendix B - Resolution Advisory Cases
- Appendix C - Traffic Advisory Summaries
- Appendix D - Data Recording Block Word Descriptions

CHAPTER TWO

EXPERIMENTAL APPROACH

This chapter discusses the organization of the evaluation project, its phasing and schedule, and the roles of the organizations that participated in or supported the project.

2.1 OVERALL APPROACH

The evaluation program was organized into three phases: pretest activities, data collection, and data analysis and report.

This project was initated 26 August 1980, with the approval of FAA contract DTFA01-80-C-10093. The contract required collection and analysis of data on the operational behavior and performance of a collision avoidance system aboard air carrier aircraft flying normal, scheduled routes. The collision avoidance system avionics and test instrumentation were provided as government furnished equipment (GFE). The selected system was being built by Dalmo Victor Operations of Bell Aerospace Textron and was subjected to engineering accpetance and to laboratory and flight tests at the FAA Technical Center prior to delivery for this test. Two sets of avionics were available for the operational flight tests.

Upon delivery, the avionics systems were installed in two air carrier aircraft which were flown in regular service until at least 900 hours of flight time had been monitored by the collision avoidance system. During this 900-hour time frame, a group of volunteer observers, who were skilled in jet transport operations, flew aboard the test aircraft as cockpit observers to provide a subjective evaluation of the performance and utility of the system. The system was installed so that the flight crew was not aware of the system display indications but the observers could see the system displays and the aircraft flight instruments and hear the radio conversations between the flight crew and Air Traffic Control (ATC).

During the data analysis the electronically recorded data from the system were correlated with the cockpit observer comments to develop a picture of the performance and utility of the collision avoidance system.

The activities within each phase are explained in more detail in the following sections.

2.2 PHASE I - PRETEST ACTIVITIES

During this period the major efforts of the project included planning, defining, and formalizing the relationship of the test participants; designing, fabricating, and testing the installation hardware; and developing the data extraction and analysis techniques and software.

Three interrelated activities were concurrently started at the beginning of the project: (1) identification of the test area, (2) selection of the air carrier partner, and (3) preparation of the test plan. A preliminary test plan had been prepared in June 1979 under contract DOT-FA78-WR-4091 and published as ARINC Research Publication No. 1343-01-2-1936. That document provided a starting point for preparation of the actual flight test plan inasmuch as it laid out the test concept (generally as outlined in Section 2.1 above) and defined test area selection criteria and test airline selection criteria.

2.2.1 Test Area Selection

The test area selection factors were (1) terminal to en-route time ratio, (2) airspace traffic density, and (3) weather. Because the major exposure to midair collision occurs in terminal area airspace*, it was desirable that the test airspace and route structure maximize the exposure of the test aircraft. Therefore, short route segments (i.e., relatively more time in low altitude airspace) were desired. Typically, an air carrier aircraft will spend 8 to 10 minutes at lower altitudes when departing an airport, and 8 to 10 minutes at low altitudes during arrival. Route segments of 40 minutes would give a 1:1 ratio of enroute-to-terminal airspace and 60-minute route segments would give a 2:1 ratio. The routing for the two test aircraft is shown in Tables 2-1 and 2-2.** The tables give scheduled block times, which should be reduced by about 15 minutes (taxi time) to estimate flight time. Aircraft Number 1 had an average segment time of 70 minutes and an average flight time of 55 minutes. With 20 minutes in lower airspace, it had an enroute-to-terminal ratio of 1.75:1. Similarly, aircraft Number 2, with an average segment time of 78 minutes had a ratio of 2.15:1. These times are probably representative of air carrier operations in general.

While the ratio of enroute-to-terminal time is important, the traffic density of the terminal airspace has a relevant bearing on the exposure of the test aircraft. Table 2-4 ranks the airports in the test area by annual air carrier enplanements and annual aircraft operations. These airports represented a wide spread of traffic volume, both in enplaned passengers and flight operations. The flight operations, which are better indications of traffic density, ranged from a high average of more than 2000 per day (ORD) to slightly more than 200 per day (HTS). Therefore, it is reasonable to conclude that the test aircraft experienced both high-

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*NTSB data.

**Location identifiers are shown in Table 2-3.

Table 2-1. AIRCRAFT NUMBER 1 (B-727-200) SCHEDULED ROUTE AND BLOCK TIMES

Day	Route	Scheduled Block Time
1	GSO-DCA-ORF-EWR-ORF-CLT-IAH-CLT-ORF-EWR	10 hours 21 minutes
2	EWR-BOS-GSO-CLT-TPA-CLT-GSO-BOS-ORF	8 hours 59 minutes
3	ORF-CLT-DFW-CLT-ORF-RIC-ORD-SDF-TRI	9 hours 55 minutes
4	TRI-CLT-TPA-CLT-ORD-CLT-TPA-CLT-GSO	9 hours 31 minutes

Table 2-2. AIRCRAFT NUMBER 2 (B-727-100) SCHEDULED ROUTE AND BLOCK TIMES

Day	Route	Scheduled Block Time
1	ORF-ATL-ORF-DCA-CVG-DEN-CVG-DCA	10 hours 58 minutes
2	DCA-SDF-DEN-SDF-DCA-GSO-INT	8 hours 28 minutes
3	INT-TRI-HTS-SDF-ORD-RIC-CLT-DFW-GSO-ORF	10 hours 6 minutes
4	ORF-GSO-BNA-DEN-BNA-GSO-PIT-CLT-MIA	10 hours 10 minutes
5	MIA-CLT-MCO-CLT-ROA-ORD-HTS-ROA-GSO	9 hours 1 minute
6	GSO-RDU-DFW-RDU-GSO-DFW-CLT-RDU-ORF	11 hours 14 minutes

Table 2-3. LOCATION IDENTIFIERS
ATL - Altanta, Georgia
BOS - Boston, Massachusetts
BNA - Nashville, Tennessee
CLT - Charlotte, North Carolina
CVG - Cincinnati, Ohio
DCA - Washington, D.C.
DEN - Denver, Colorado
DFW - Dallas-Ft. Worth, Texas
EWR - Newark, New Jersey
GSO - Greensboro, North Carolina
HTS - Huntington, West Virginia
IAH - Houston, Texas
INT - Winston-Salem, North Carolina
MCO - Orlando, Florida
MIA - Miami, Florida
ORD - Chicago, Illinois
ORF - Norfolk, Virginia
PIT - Pittsburgh, Pennsylvania
RDU - Raleigh-Durham, North Carolina
RIC - Richmond, Virginia
ROA - Roanoke, Virginia
SDF - Louisville, Kentucky
TPA - Tampa, Florida
TRI - Tricities, Tennessee

Table 2-4. TRAFFIC STATISTICS OF TEST AREA AIRPORTS

Rank (1)	Location	Operations Thousands (2)	Percent (3)	Rank (1)	Location	Operations Thousands (2)	Percent (3)
1	ORD	736	6.85	43	CVG	131	.52
2	ATL	594	6.47	47	CLT	223	.48
6	DFW	436	3.42	52	BNA	230	.39
7	DEN	482	3.01	58	SDF	198	.36
9	MIA	379	2.79	67	ORF	158	.29
10	BOS	356	2.31	69	RDU	207	.28
11	DCA	351	2.20	76	GSO	169	.22
15	IAH	296	1.67	78	RIC	160	.21
16	PIT	347	1.64	90	ROA	130	.14
21	EWR	211	1.40	(4)	TRI	152	.08(5)
24	TPA	242	1.15	(4)	HTS	79	.05(5)
28	MCO	133	.95	(4)	INT	102	.02(5)

(1) Rank by passenger enplanements.

(2) Total operations (air carrier + air taxi + commercial + general aviation + military. All figures are 1979 actual counts except where indicated.

(3) Percent of total national passenger enplanements.

(4) Rank is between 101 and 659.

(5) 1977 Ranking.

Source: FAA-APO-80-10, Terminal Area Forecasts FY 1981-1992, Federal Aviation Administration February 1981

and low-density traffic situations.

Weather, especially the presence of low clouds and low visibility, affects traffic densities and the separation standards applied by ATC. During periods of good visibility, ATC often issues "visual approach" clearances to expedite the landing of air carrier (and other controlled) traffic. Pilots generally accept visual clearances even when they know that they will have less than normal Instrument Flight Rules (IFR) clearance from other aircraft. The logic used in the collision avoidance system was designed to accept IFR separation as safe and normally would not provide resolution advisories to the crew when those separation conditions were satisfied. Therefore, we expected to see more traffic advisories and resolution advisories during "visual" operations. This expectation was fulfilled when the weather in January and February 1982 was poor over most of the test area for a long period, permitting fewer visual operations, and the advisory rate (advisories per hour) decreased.

2.2.2 Test Air Carrier Selection

The selected air carrier, Piedmont Airlines, met all the criteria established in the preliminary test plan. The selection factors were as follows:

- Operates 727 or larger aircraft
- Has short flight segments
- Permits frequent access to test aircraft
- Permits observers on flight deck
- Shows positive attitude toward test objectives

A sixth factor was added at the start of this project: operates its own engineering and maintenance activity.

The requirement for Boeing 727 or larger aircraft was dictated by the space requirement for the system, the requirement that the display be out of the view of the flight crew, and the requirement for up to two observers on a flight. The 727 was the preferred aircraft because it could be expected to operate over shorter routes than the 747, DC-8, DC-10 or L-1011. Additionally, the 727 is a more widely used aircraft, which permitted selection from a larger number of air carriers.

Two factors tended to eliminate the major trunk carriers from selection as the test carrier. First, the short flight segment requirement (see Section 2.2.1 above) was better met by the local service carriers who concentrate on this market. Trunk carriers tend to use their 727 and larger aircraft on longer flights and use DC-9 or 737 aircraft for short-haul service.

The requirement for frequent access to the test aircraft also directed the selection toward local service carriers. The tape recorders used for collection of data required frequent access to exchange tape cartridges. The logistic support of the data collection and scheduling observers aboard the test aircraft would have been unmanageable if the selected air carrier operated a large fleet of 727s. At the time the selection was made, Piedmont Airlines operated six 727s over a route structure that included a landing in Norfolk, Virginia, five out of six days. Therefore, Norfolk, where Piedmont maintained a major avionics shop, was an ideal point for changing tape cartridges and checking the system operation.

Subsequent to the air carrier selection and before the start of the data collection, Piedmont Airlines bought four more 727s. One of the purchased aircraft was the first one to have the collision avoidance system installed. The second system was installed in an aircraft already in operation. The newly purchased aircraft were Boeing 727-200s; those already in service were 727-100s. The aircraft were assigned to separate routings as shown in Tables 2-1 and 2-2.

Access to air carrier cockpits is controlled by both the individual air carrier and the FAA. The FAA will authorize access to the cockpit whenever the person so authorized has valid business and the authorization is requested by the air carrier. Each air carrier has its own policy governing access to the cockpit, and each request is evaluated individually. Because this program required a number of technicians and flight observers to spend a considerable amount of time aboard the test aircraft, the selected air carrier had to permit such personnel. Piedmont Airlines and its flight operations department were very cooperative in granting the authorizations.

This positive attitude toward the test observers was one facet of the positive corporate attitude sought for this test. The cooperative attitude of the Flight Operations Department, Engineering Department, and Avionics Division at Piedmont Airlines assured prompt attention and correction of any problems. That attitude of eager cooperation was matched by the competent performance of every person associated with the project. The project would not otherwise have been successfully completed.

The in-house engineering and maintenance capability of Piedmont Airlines proved to be the critical factor in meeting the milestones for design, installation, and certification of the modification of the aircraft by addition of the separation assurance system. This integrated engineering and maintenance organization permitted advance selection of the airframes to be modified and assured that the modification would be completed on time with no extra aircraft downtime. It also permitted such economies as combination of a test flight to check system operation with a scheduled maintenance test flight.

2.2.3 Definition of Available Data

One of the early efforts in this project was the definition of available data and data sources. Two types of data were considered: data to support the modification of the test aircraft, and data to support the data collection and analysis.

The first category of data included equipment design and fabrication data, hardware tests and test results, definition of the detection and resolution logic and data on its performance, aircraft data, and data on the design and performance of the test support equipment (clock and recorder). The application for the aircraft supplemental type certificate required supporting documenting from all these sources.

The data collection and analysis work required information on the types and formats of data developed by the collision avoidance system and recorded by the recorder. The types and formats of these data are discussed in Chapter Four.

2.2.4 Development of the Test Plan

The test plan is the document that sets out the objectives and scope of the project, defines the test concept, defines the test participants and coordination procedures, outlines the data collection and analysis concept, and lays out the schedule.

The test plan include two appendixes: observer records and installation drawings. The appendixes were designed to expand into two other documents. The observer record was expanded to become the observer instructions for distributin to each cockpit observer. The installation drawings formed the basis of the drawings package submitted for the STC.

The test plan was published as ARINC Research Publication No. 1389-01-TR2359.

2.2.5 Collection of System Design Data

The identification of data sources (Section 2.2.3 above) proved very helpful in our collection of system design data for use in designing the installation kits and preparing the application for STC. Hardware design data were provided by the equipment manufacturer, Dalmo Victor Operations of Bell Aerospace Textron; software design data were provided by MITRE Corporation; integration data were provided by MIT Lincoln Laboratory; and functional test data and some installation experience data were provided by the FAA Technical Center. All of these organizations were in the process of developing or validating these data, which meant constant coordination and revisions.

2.2.6 Design of Installation Kit

The operational test project was only one segment of the overall collision avoidance system development program. Therefore, the avionics systems and parts of the installation hardware were required to support engineering flight tests and electromegnetic compatibility tests at the FAA Technical Center up until the time the data collection phase of this project was scheduled to start. The test aircraft could not be removed from operational service to make the necessary modifications at the time the avionics were received. A phased aircraft modification program was therefore developed to overcome those restrictions.

Installation of the antennas, antenna control cables, RF cables, and antenna heating system required removal of major access panels and sheet-metal work that could be accomplished only in the maintenance hangar. Therefore, the installation designer developed those items as a kit that was installed on the aircraft during normal maintenance checks when the majority of the inspection panels were removed for other work.

The equipment racks, inter-box cabling, and avionics boxes were installed on two successive overnight work shifts. The installation designer considered this in the development of his kits, which were made up in advance and held for the availability of the avionics.

This two-step appraoch permitted modification of the aircraft with no down-time charged to the project.

2.2.7 Development of Certification Procedures

At the outset of the project it was expected that the collision avoidance system would require special quality assurance procedures to permit inssuance of the supplemental type certification. During coordination meetings between Piedmont Airlines and the FAA Southern Region, an agreement was reached to certify this modification under FAA Order 8110.10B, FAA Approvals of Major Modifications/Alterations. This was accomplished through preparation of a Piedmont Airlines engineering order, inspection of the modification by an FAA inspector, and issuance of an STC for the two aircraft that were modified.

2.3 PHASE II DATA COLLECTION

The data collection phase of the project included the fabrication of the installation hardware, modification of the aircraft installation and checkout of the avionics systems, certification by the FAA development of the data extraction and analysis programs, and the collection of the data.

2.3.1 Fabrication of Installation Kits

The installation kits were fabricated in two parts. The antenna installation hardware was largely custom fabricated at the time the antennas were installed on the aircraft. The top antenna and its associated

doubler plate were mounted on the airframe. Bleed air was piped from the top VHF antenna hot air supply and connected to the TCAS antenna. The antenna cables were installed between the top of the aircraft and the electrical and electronic (E&E) compartment. The lower antenna did not require deicing protection or a doubler plate.

The first aircraft to have antennas installed was inspected by the FAA and returned to service while awaiting delivery of the collision avoidance avionics.

The wiring harnesses for the avionics and displays were made up by the Piedmont Airlines maintenance shop. Each wire was stamped with its identification and the completed harnesses were checked for continuity and integrity. The equipment racks and associated sheet metal were installed during a normal overnight stop at Winston-Salem, and the wiring harnesses and avionics were installed during a second overnight stop. The aircraft was returned to service the next morning with no unusal downtime.

The second aircraft was actually the first to become operational. It was going through an extensive overhaul program and was at the maintenance facility long enough to complete the installation, including system operation checks. The equipment was tested in conjunction with a flight test for other maintenance work accomplished during the overhaul. While the collision avoidance system installation did not require a flight test, the opportunity was useful in confirming the installation.

2.3.2 Development of Data Extraction Programs

The test installation included a digital data recorder that recorded 14 different types of data directly from the CAS processor whenever an aircraft penetrated a defined airspace in the vicinity of the equipped aircraft. Some of these data blocks were concerned with the radio frequency portions of the hardware and were not analyzed in this project. Data blocks shown in Table 2-5 were the only blocks that contained data required for this project.

The data were recorded on special cassettes in nine-track, computer-industry-compatible format. The data extraction programs were designed to extract the data from the cassettes, examine the data for integrity, develop a tape index with an associated printout, and copy the data from cassette to standard tape for filing and later detailed analysis.

2.3.3 Collection of Data

The collection of data constituted the major activity during Phase II of the project; however, it was primarily a routine activity. Observers were scheduled on specific flights, data tape cassettes were collected and processed daily, and blank tape cassettes were returned for reinstallation on the aircraft.

Table 2-5. RECORDED DATA BLOCKS	
Record Title	**Description**
Data Loss	Recorded whenever data blocks were lost due to insufficient buffer space or recording capability
Beginning of Scan	Recorded own-aircraft status table at the beginning of each one second scan (cycle of the TCAS algorithm)
Error Counts	Recorded the number of times that various error conditions or other unusual events occurred
CAS Intruder Track File Record	Recorded entire set of active tracks (ATCRBS and Mode S) at the end of the CAS scan
Display Vector	Recorded the CAS display vector at the end of the CAS cycle
Threat File Record	Recorded entire threat file at the end of the CAS scan

2.4 PHASE III, DATA ANALYSIS AND REPORT

Phase III of the project encompassed the analysis of the data collected in Phase II and preparation of this report.

2.4.1 Data Analysis

Two types of analysis output were planned: a case study of each resolution advisory and statistical data on the performance of the system.

The case studies described the conflict geometry and recorded closure rates, ranges, altitudes, traffic densities, types of resolution advisories, time and duration of the advisory, and changes in type of advisory. These data were used to generate a set of plots for each resolution advisory and were available to examine those traffic advisories that were selected for special study on the basis of information contained on the tape index or in observer comments.

The observer comments were correlated with the recorded data to define the geographic location of the conflict better and provide an evlauation of the effect of the incident on the flight crew and on the ATC system. These case studies of resolution advisories are presented in Appendix B.

In addition to the case studies, statistics were accumulated to determine advisory rates and distributions on the basis of own altitude, initial bearing and range of intruder, and airspace density. These results are presented in Chapter Five.

CHAPTER THREE

TEST INSTALLATION

This flight evaluation was conducted to assess the operational effect of a TCAS installed aboard air carrier aircraft in normal scheduled operation. Under contract to the FAA SRDS, Dalmo Victor provided TCAS avionics and light weight data recording equipment packaged along lines compatible with air carrier installation. Three sets of TCAS avionics were delivered to the FAA for both engineering and operational evaluations. Engineering tests were conducted at the FAA Technical Center aboard one of its Boeing 727 flying laboratories. The equipment was mounted in special racks, secured to cargo pallets in the main cabin of the aircraft. During planned encounters, the installation was continuously manned and monitored by recording systems. The FAA Technical Center engineering tests provided data to confirm that the system met the requirements of ER250-2 and was suitable for installation in air carrier aircraft. After testing at the Technical Center, two sets of TCAS avionics were used in the operational flight test and were installed in the avionics compartments of two Boeing 727s in commercial passenger service. The installation of the sets is discussed in this chapter.

3.1 AIRCRAFT

The aircraft selected for this test program was the Boeing 727. It offered sufficient space in the avionics compartment for the test avionics and data collection equipment and sufficient space in the top section of the aircraft for mounting the directional antenna, assuming the aircraft was not fitted with a life raft. The Boeing 727 cockpit has two forward-facing observer seats and space to mount the displays away from the crew's normal view.

In order to take maximum possible advantage of the air carrier's route structure, one Boeing 727-100 and one 727-200 (stretched version) aircraft were selected for installation of the two sets of TCAS avionics. This provided the route variety and coverage requirements discussed in Chapter Two. The sets were installed at Piedmont Airlines facility in Winston-Salem, North Carolina, during routine inspection and maintenance cycles.

3.2 AVIONICS

The TCAS avionics and test equipment consisted of the following items for each installation:

Unit	Approximate Size (Inches)	Approximate Weight (Pounds)	Number
RF Processor	10.0 x 7.76 x 12.5	35	1
Antenna	8.0 dia. x 3.4 high	5	2
Display/Control Unit	6.30 x 8.13 x 14.0	15	1
IVSI Display	3ATI		1
Data Recorder	8.0 x 9.70 x 14.50	30	1
Clock	17.0 x 3.50 x 11.10	17.25	1

3.3 RECORDER

A high-performance, ruggedized, light-weight, digital tape recorder and controller was installed in the electrical and electronics (E&E) compartment to collect TCAS performance data. The recorder used a 9-track parallel industry-compatible format. It was easily accessible for removal and replacement of data tape cassettes and for periodic maintenance. Frequent changing of tapes and clock updates were accomplished by ARINC Research observers and by Piedmont avionics personnel in Norfolk, Virginia. Data tapes were shipped via scheduled Piedmont flights to Washington's National Airport for pickup by ARINC Research almost every day.

3.4 DISPLAYS

The TCAS CRT and IVSI displays delivered by Dalmo Victor are adaptations of existing displays. They were not optimized for air carrier cockpit installation and do not represent production type displays. For this test the displays were installed on the left side of the cockpit on a specially constructed rack and were for use only by the project observers. The displays were not in the normal view of any member of the flight crew. The rack was mounted on the raceway to the left of the forward jumpseat and forward of the rear jumpseat. Observers could ride in either jumpseat and observe TCAS.

Radio and cockpit communications and TCAS audio alerts were monitored by the project observer. The TCAS audio alert could be heard only on the observer's headset. They could not be heard by any member of the flight crew.

3.5 CLOCK

The test installation included a commercial day, date, time-of-day clock that would mark the data tape with the time of each advisory incident. For easy access the clock was mounted in a specially fabricated rack next to the door of the E&E compartment. A special cover was fabricated to guard the controls from inadvertment disturbance. The clock contained back-up batteries to supply power during periods when aircraft power was unavailable.

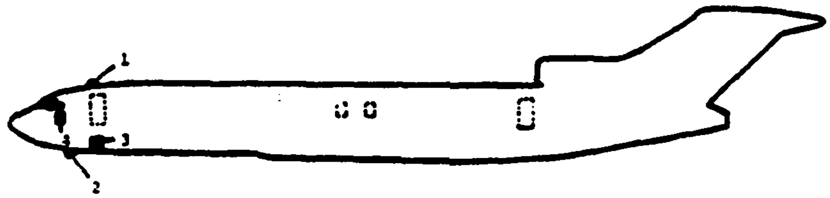
3.6 DESIGN

Under contract to the FAA, ARINC Research Corporation was responsible for designing, managing, and conducting the TCAS operational flight test. The installation was designed by Piedmont Airlines. Coordination between the manufacturer and air carrier was provided by ARINC Research. Rather than direct the design of a totally specialized installation kit, we requested that the avionics be packaged to meet ARINC standards where possible. To the extent practicable for the installation of pre-production TCAS avionics and specialized test equipment, the installation conformed to standard industry practices and ARINC specifications. While that did not guarantee satisfy action of certification requirements, conformance to such practices provided a basis for applying for certification of the installation. The design was subject to final approval by the FAA regional office.

Manufacturers and air carrier engineering drawings and wiring lists were coordinated among ARINC Research, Dalmo Victor, and Piedmont. Subsequent detail design and installation changes were made to ensure system/aircraft compatibility and reduce the need for special modifications.

The upper TCAS antenna required some structural modifications and used an existing VHF antenna anti-ice bleed air source. The lower antenna was installed at an existing antenna cutout and required no structural alterations. Standard shelving was used for the Dalmo Victor TCAS processor and rack. With small design modifications, a standard ARINC rack was used for the data recorder/controller unit. A special mount was designed to provide accessibility to the digital time-of-day clock. A special mount was also required to install the displays away from the normal view of the aircrew. Usual precautions were taken by Dalmo Victor to preclude unusual electrical loads and electromagnetic interference. Circuit breakers for separate components of TCAS avionics and test equipment were provided in the cockpit. The general location of components is shown in Figure 3-1.

The drawings that accompanied the application for an STC were working drawings, but contained all information on the design of installations and interfaces with existing aircraft systems. Aircraft electrical and avionics systems involved included 115V, 28V, air-ground switch circuit, pressure altitude encoder, radar altimeter, ATCRBS Mode \ Code, and the



1. Top Antenna
2. Bottom Antenna
3. RF/Processor Unit
4. Control/Display

Figure 3-1. TCAS EQUIPMENT LOCATIONS

transponder-DME mutual suppression bus. The system interfaces are shown in Figure 3-2.

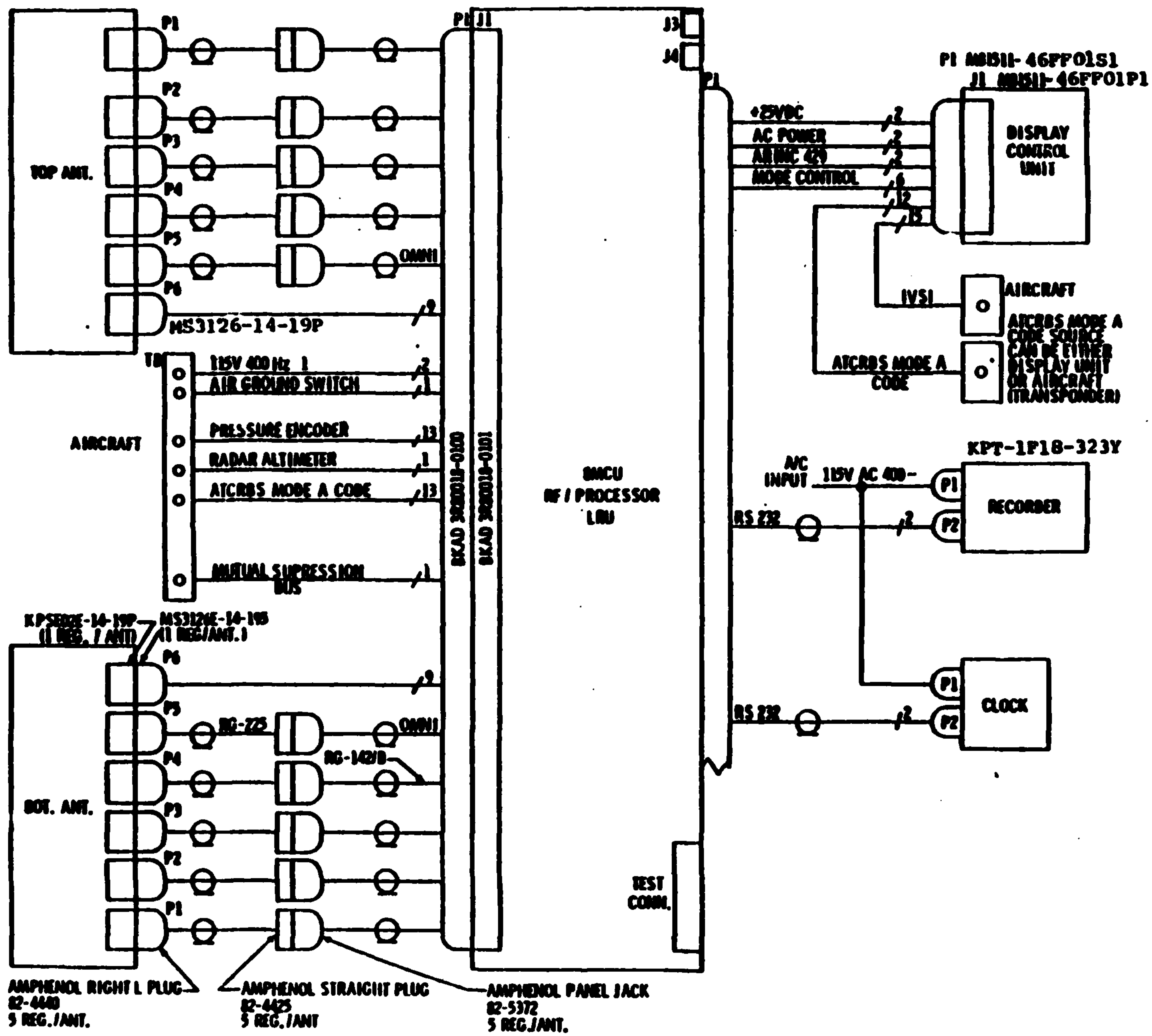
The engineering design for this installation required 408 hours of senior engineer time. The fabrication and installation labor requirements showed a good degree of learning between aircraft number 1 and aircraft number 2. The first aircraft required 317.0 hours of avionics technician labor and 89.2 hours of sheet metal work for a total of 406.8 manhours of installation labor. The second aircraft required 261.3 hours of avionics technician time and 34.5 hours of sheet metal work for a total of 295.8 hours.

3.7 CERTIFICATION

Requirements for certification of the installation of TCAS avionics and test equipment were reviewed by FAA Southern Regional Headquarters. Participants included representatives from the FAA SRDS, ARINC Research Corporation, the Avionics and Engineering Departments of Piedmont Airlines, and the FAA Southern Region. Rather than following specialized certification procedures for experimental equipment, we directed our development and installation design efforts at approximating a normal air carrier installation and meeting requirements for a Supplemental Type Certification (STC). Submittal of test data and successful com-

CAS SYSTEM INTERFACE DIAGRAM

NOTE: CONNECTORS FOR TOP ANTENNAS ARE SAME AS BOTTOM ANTENNAS



pliance with applicable requirements as determined by compliance, compatibility, and conformity inspections were sufficient for issuance of an STC. A flight test aboard Piedmont aircraft prior to testing of TCAS in scheduled operation was not required, but was performed.

Installation practices, inspections, system functional checks, and electromagnetic interference tests at Piedmont's facility in Winston-Salem resulted in the issuance of the STCs. Because it was convenient and desirable to do so during the flight checks of other systems, the first installation of TCAS avionics and data recording equipment was tested in flight aboard N539PS prior to its entry into scheduled operations for Piedmont Airlines. This flight test confirmed the system operation and non-interference with other aircraft control, naivgation, communication, and identification systems.

CHAPTER FOUR

DATA COLLECTION METHOD

Data requirements and available data sources were analyzed early in the project planning phase. Three major sources of data were identified: (1) performance data produced within the collision avoidance system processor on board the aircraft, (2) opinions of observers on the aircraft, and (3) aircraft position data produced from a ground tracking system. Collection techniques were outlined for each source of data and the best source, from an ease-of-collection viewpoint, was selected for each type of data.

The practical aspects of collecting, extracting, and correlating data from the ATC system radars, the only system that covered the entire test area, required a level of logistic support that was beyond the resources of the project. Further, most of the data available through the ground radar systems were duplicated in the data recorded aboard the test aircraft. A decision was therefore made to collect only observer data and data recorded aboard the aircraft.

The test aircraft did not receive special handling by the ATC system. There were no special transponder codes, flight numbers, or call signs assigned to the test aircraft. While the test program was announced in various television reports, newspapers, and trade magazines, it is doubtful that any controller was aware that the test aircraft was equipped with a collision avoidance system.

While the flight crew members were aware that the aircraft was equipped with a CAS they were not aware of any advisories that were being generated by the display. Since there was no pilot interaction with the system, the flight crews did not operate the test aircraft any differently from other Piedmont B-727 aircraft.

4.1 AUTOMATIC DATA RECORDING

The CAS installation included two pieces of equipment that were unique to the test and would not be required in operational installations. Those were a tape recorder and a time-of-day clock, both used solely to collect time-marked data on conflict situations indicated by the CAS equipment. A block diagram of the system is shown in Figure 4-1; details of the installation were given in Chapter Three.

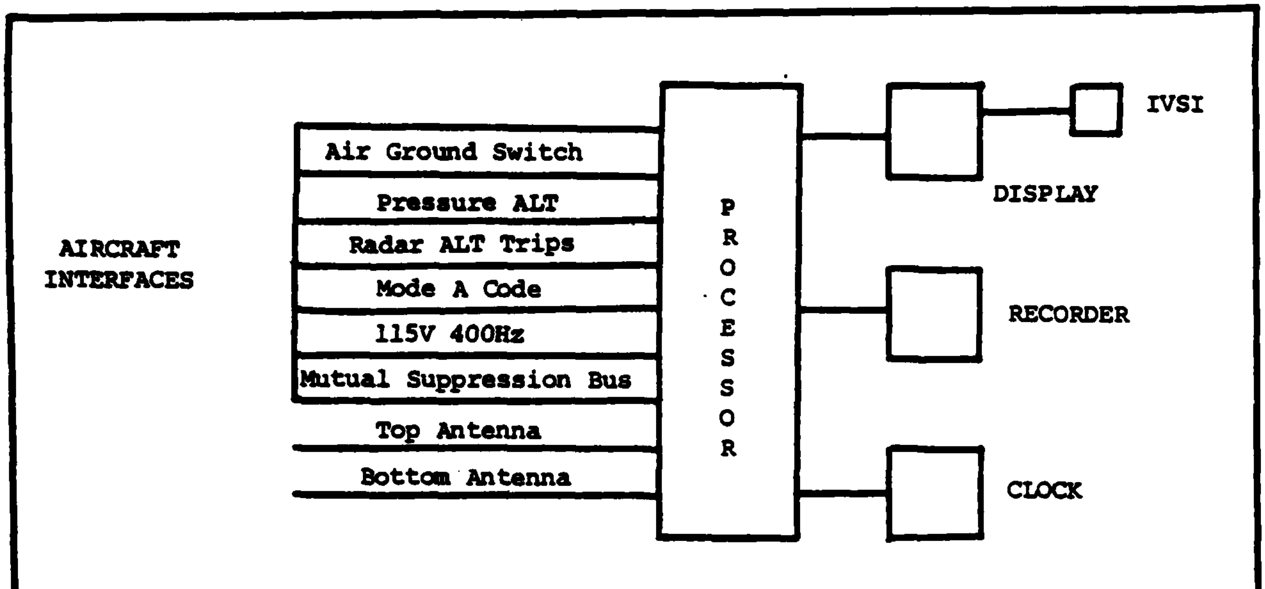


Figure 4-1. CAS SYSTEM INTERFACE

The CAS processor used for this test provided a special RS-232 output to the recorder, which permitted transfer of both surveillance and CAS data files to the recorder at a one-second update rate. The clock provided time-of-day data to time-stamp the data received from the processor. Although fifteen data blocks were generated each cycle, the data analysis program required only seven of the blocks. The seven data blocks and their contents are briefly described in Table 4-1. Each word in each data block is described in Appendix D.

The only interaction possible between the observer and data recorder was the de-activation of the power circuit breaker located in the cockpit. All other recorders controls were located on the recorder, which was installed in the E&E compartment.

Table 4-1. DATA BLOCK DESCRIPTIONS

BLOCK 0

Title: Data Loss

Description: This is recorded by the real time data recording software itself whenever data blocks are lost due to insufficient buffer space or recording capability. This block is recorded at the point where the missing blocks would have appeared.

BLOCK 1

Title: Beginning of Scan (VERSION 8)

Description: This records the own-aircraft status table at the beginning of each scan. Recording is performed by the CAS subsystem (note change from earlier versions) when it performs its beginning-of-scan initialization.

BLOCK 2

Title: Error Counts

Description: This records the error count array. These counters keep track of the number of times that various error conditions or other unusual events occur. They are set to zero at system initialization or restart. This block is recorded at the same time as block #1.

BLOCK 10

Title: CAS Intruder Track File Record (VERSION 8)

Description: The entire set of active CAS intruder track file recorded in each block 10, and so typically several block 10 recordings will appear together on the data tape. Names in parentheses are those used in the CAS logic description to reference these variables.

contd.

Table 4-1. DATA BLOCK DESCRIPTIONS (contd.)

BLOCK 11

Title: Display Vector (VERSION 8)

Description: This records the CAS display vector at the end of the CAS cycle, as it was sent to the display generation software.

BLOCK 13

Title: Threat File Record (VERSION 8)

Description: Each block 13 records one entry in the CAS threat file. The entire threat file is recorded at the end of the CAS cycle by means of several block 13 records. Names in parentheses are those used to refer to these qunatities in the CAS logic description.

CHAPTER FIVE

REPRESENTATIVE CONFLICT CASES

This chapter presents five cases from among the 32 resolution advisory cases observed. The five cases represent 25 percent of the resolution advisories related to airborne aircraft and were selected to provide samples of characteristic system operation.

Each case is accompanied by six data plots, prepared from the data recorded during the conflict. One of these plots represents the relative bearing and range of the intruder aircraft during the incident. The data are presented in a plan view format: a turn by either aircraft causes a change in relative bearing. Each symbol on this chart represents a one second update of the data, the same update rate used on all charts.

The remainder of the plots are x-y plots, with elapsed time from the start of the encounter plotted on the x-axis. X-axis values are shown on the lower of the charts on each page.

The remaining plots provide a record of the following sets of data:

- Tau values. Both the range tau (TAUR) and vertical tau (TAUV) are plotted on the same chart. The y-axis scale is in seconds. A dashed line across the chart shows the TAUR value for generation of a resolution advisory for the case.

- Altitude separation. Two types of separation data are plotted: current altitude separation (A) and altitude separation projected at point of closest approach (VMD). The threat detection threshold is shown by a dashed line. Altitude separation is always given as a positive value and therefore gives no indication whether the intruder was above or below the test aircraft.

- Range information. Two types of range information are shown: Range (R) and range rate (RDOT). The range is plotted in nautical miles with the scale on the left of the plot. Range is always shown as a positive number. Range rate is plotted in feet per second with the scale on the right. Range rate may be either a positive or negative value.

- Vertical rates. This chart shows the vertical rates of the test aircraft (ZDOWN) and the intruder (ZDINT) in feet per second. The values may be either positive or negative.

- Range and altitude separation. Three data elements are plotted on this chart. The range (R) between the test aircraft is in nautical miles and plotted against the right scale. The test aircraft altitude (ZOWN) and the intruder altitude (ZINT) are plotted against the left scale. The three curves plotted on this chart, together with the bearing plot, provide a very good representation of the physical encounter.

At the top of the plot is a representation of the resolution adivisories generated during the encounter. An arrow indicates a "CLIMB" or "DESCEND" advisory; an arrow with an X on the shaft indicates a "DON'T CLIMB" or DON'T DESCEND" advisory; an arrow with bars on the shaft represent a "LIMIT CLIMB" or "LIMIT DESCENT" advisory, with one bar signifiying 500 feet/minute two bars 1000 feet/minute and 3 bars 2000 feet/minute.

A vertical line is drawn on the plots to indicate the start of an advisory.

5.1 CASE 4, TAMPA FLORIDA

On the evening of 3, December 1981 an air carrier pilot was aboard Piedmont Flight 66 to observe the operation of the TCAS and evaluate its potential effect on crew duties. At approximately 6:30 pm, Flight 66, from Charlotte, N.C., to Tampa, Florida, had been cleared to descend to 4000 feet. Flight 66 was approximately 18 miles east of Tampa airport and was turning to a southerly heading. As Flight 66 passed through 4100 feet, descending at approximately 600 feet/minute, the CAS gave the observer a traffic advisory by sounding the aural alert and displaying conflicting traffic on the CRT display at 12 o'clock and 4 miles range. No traffic advisory was issued by Air Traffic Control. The intruder continued to track closer to Flight 66, still showing a 12 o'clock bearing and with range steadily decreasing. When the intruder reached the three-mile range, the TCAS aural alert sounded again and a "DON'T DESCEND" resolution advisory was displayed on the system IVSI. At that time the intruder relative altitude showed him 300 feet below Flight 66. Shortly thereafter, with Flight 66 level at 4000 feet (as cleared by ATC) the flight crew and the observer sighted the other aircraft, which passed to the left and below Flight 66.

The observer felt that the system performed as he expected in this conflict situation and that the "DON'T DESCEND" resolution advisory was correct and would not have interfered with the flight crew duties. This advisory was classified as a "preventive" advisory inasmuch as Flight 66 was not descending at the time the "DON'T DESCEND" advisory was given. The observer did not believe that the traffic advisory was useful in the encounter. He felt that the resolution advisory was given for enough in

advance to provide sufficient notice to the flight crew.

The data plots confirm the observers' account with one exception. The recorded data show that a five-second "CLIMB" advisory was given before the "DON'T DESCEND" was given. That advisory was not seen by the observer. That may have been the result of a malfunction in the display system, but inspection revealed no obvious failures, and the problem did not recur. The data plots for this encounter are shown in Figures 5-1, 5-2, and 5-3.

5.2 CASE 6, NORFOLK, VIRGINIA

In the afternoon of 21 December 1981, the test aircraft, operating as Piedmont Flight 55 was approaching the Norfolk Regional Airport from the northeast for a straight-in landing on Runway 23. When Flight 55 was approximately 10 miles northeast of the airport, ATC advised it to stop its descent at 4000 feet because of traffic crossing right to left at 3500 feet. The flight crew and observer had previsouly sighted the intruder, a DC-7 that had just departed Norfolk Naval Air Station.

The TCAS sounded the aural alert and gave a traffic advisory that first showed the intruder at 5 miles, 1 o'clock and 500 feet below the test aircraft. This target tracked toward the test aircraft and at approximately 2.5 miles a "DON'T DESCEND" resolution advisory was shown on the TCAS IVSI. The TCAS traffic display continued to provide position data that correlated to the actual positions of the aircraft. The DC-7 passed in front of and below the test aircraft, after which ATC permitted Flight 55 to resume its descent for landing.

This encounter is quite typical of those observed during the evaluation. The two aircraft had sighted each other and ATC had issued advisories to both. The safe passage was accomplished by cooperative action of both pilots and ATC. The TCAS traffic advisory first appeared after the ATC advisory and showed the apparent true relative positions of the two aircraft. The TCAS resolution advisory was compatible with the action taken by the flight crew and ATC. The observer believed that the TCAS would not have interfered with the normal duties of the flight crew.

Data plots from Case 6 are shown in Figures 5-4, 5-5 and 5-6.

5.3 CASE 7, NORFOLK, VIRGINIA

On the morning of 29 December 1981, the test aircraft was operating as Piedmont Flight 50 from Norfolk, Virginia, to Newark, New Jersey. When Flight 50 was approximately 6 miles northwest of Norfolk Regional Airport, it was directed by ATC to stop its climb at 4000 feet because of other traffic at 11 o'clock, 3 miles, at 4500 feet in a left turn. The flight crew and observer saw a Navy C-1 at the expected location. Very shortly, the TCAS aural tone alerted the observer to simultaneous traffic and resolution advisories. The traffic advisory showed traffic

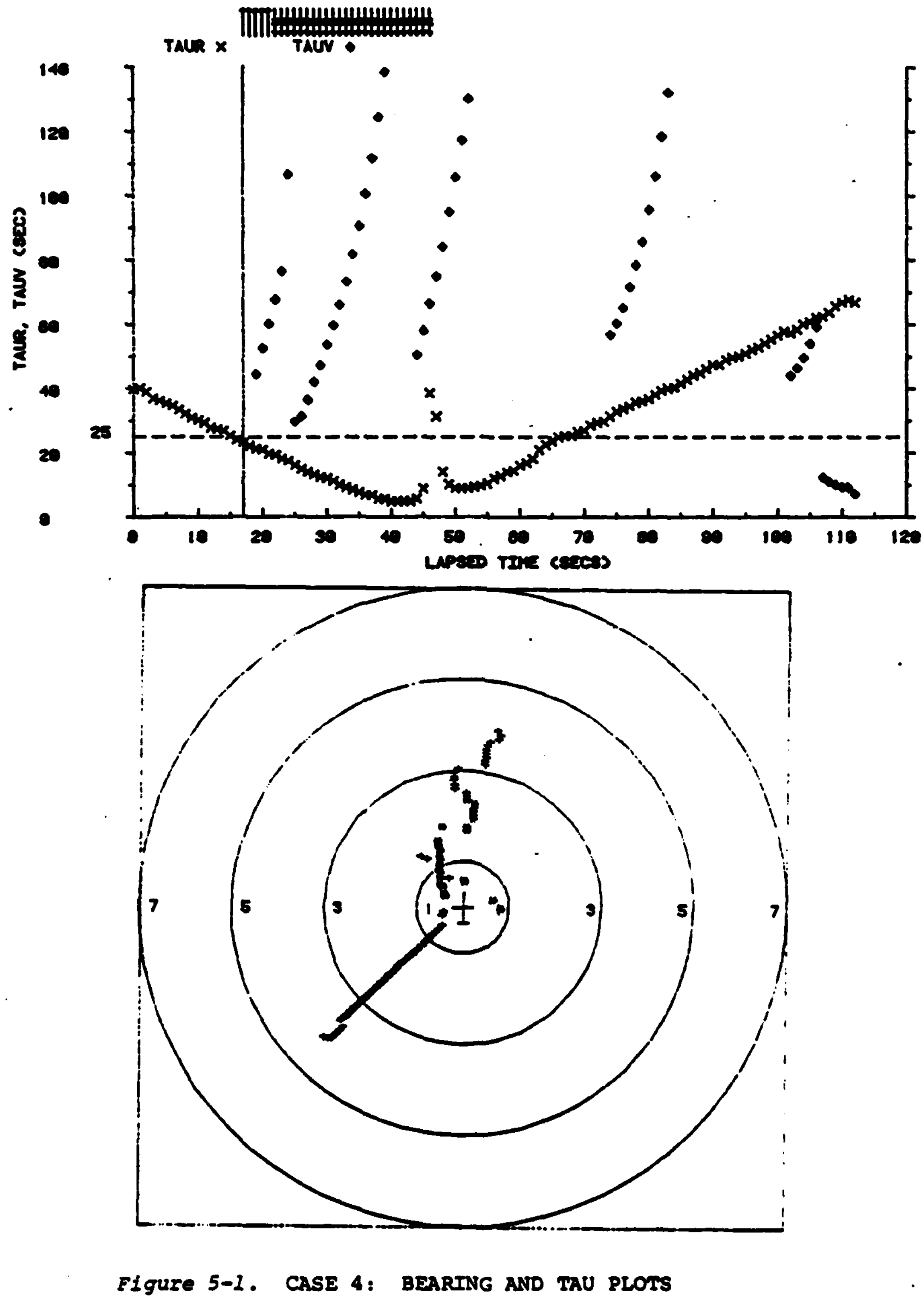


Figure 5-1. CASE 4: BEARING AND TAU PLOTS

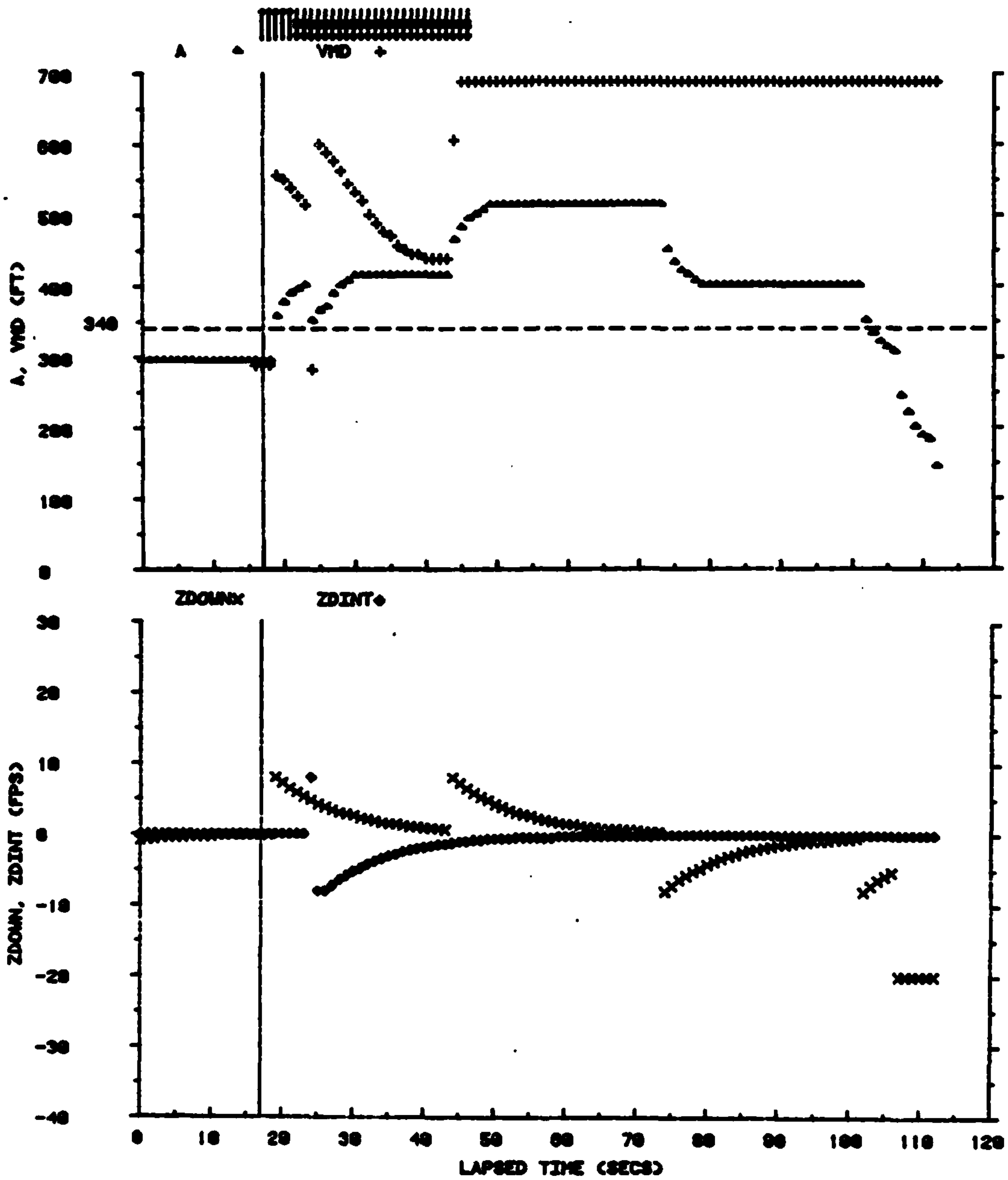


Figure 5-2. CASE 4: VERTICAL RATE AND ALTITUDE SEPARATION PLOTS

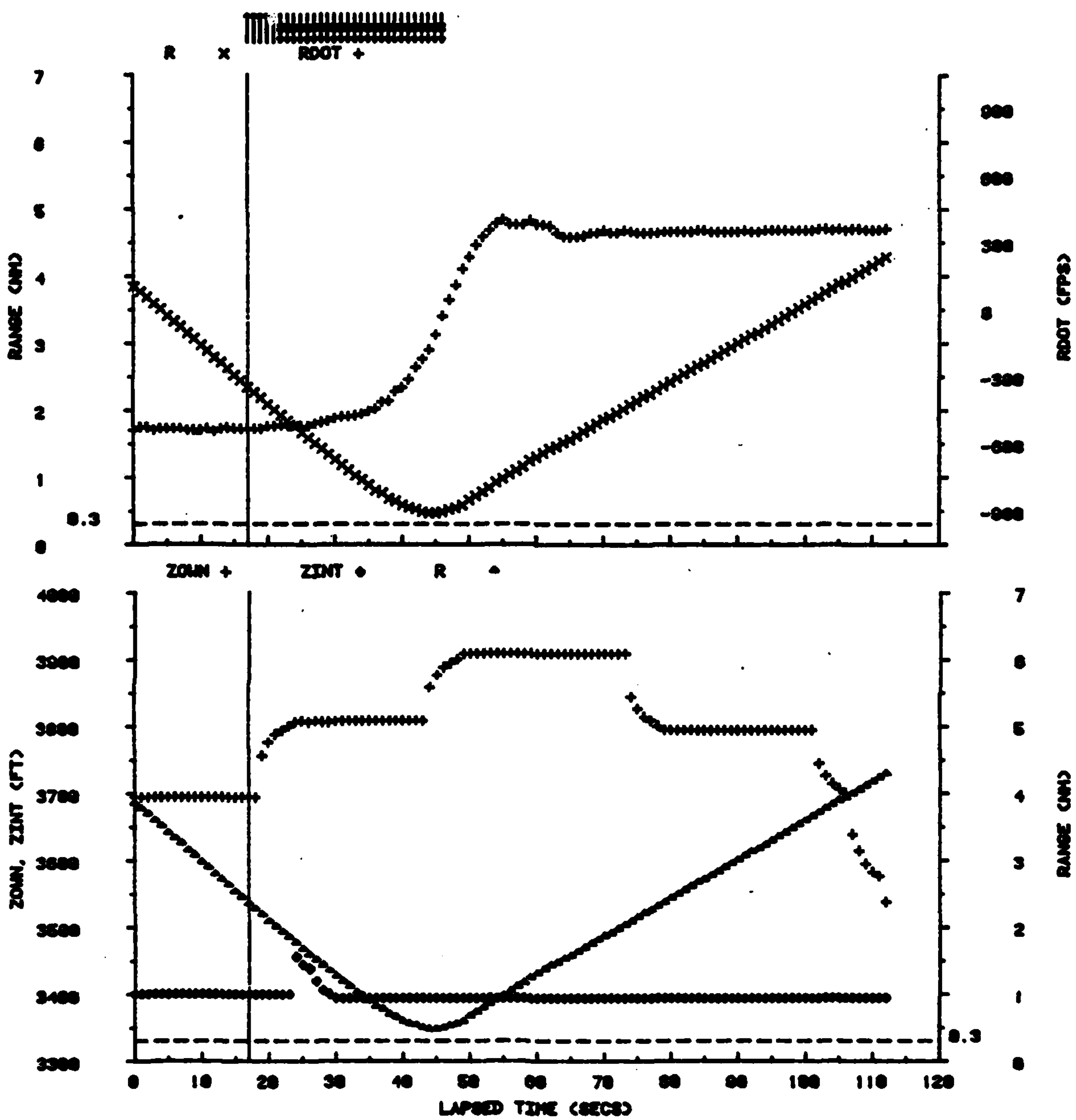


Figure 5-3. CASE 4: RANGE, RANGE RATE, AND ALTITUDE PLOTS

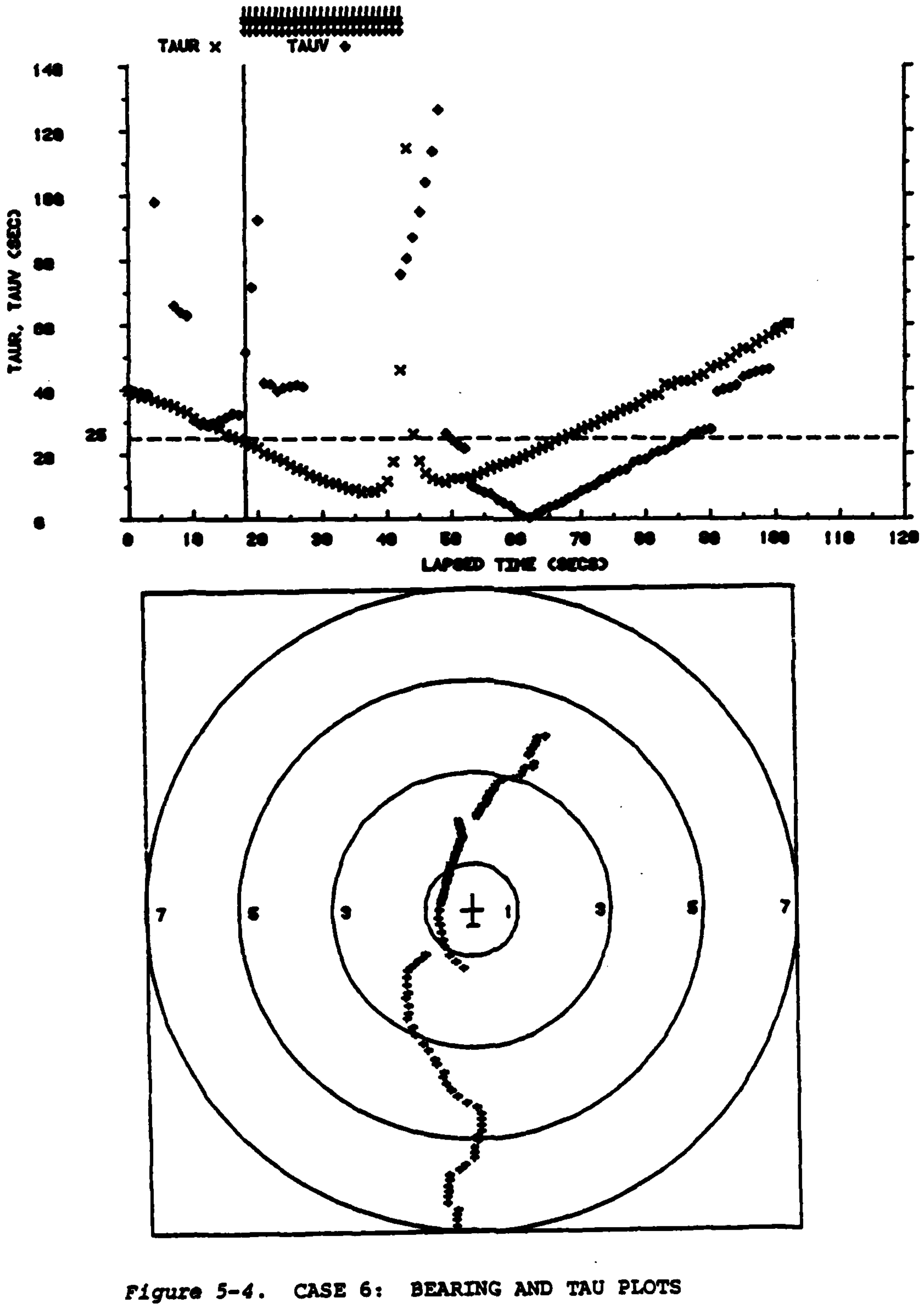


Figure 5-4. CASE 6: BEARING AND TAU PLOTS

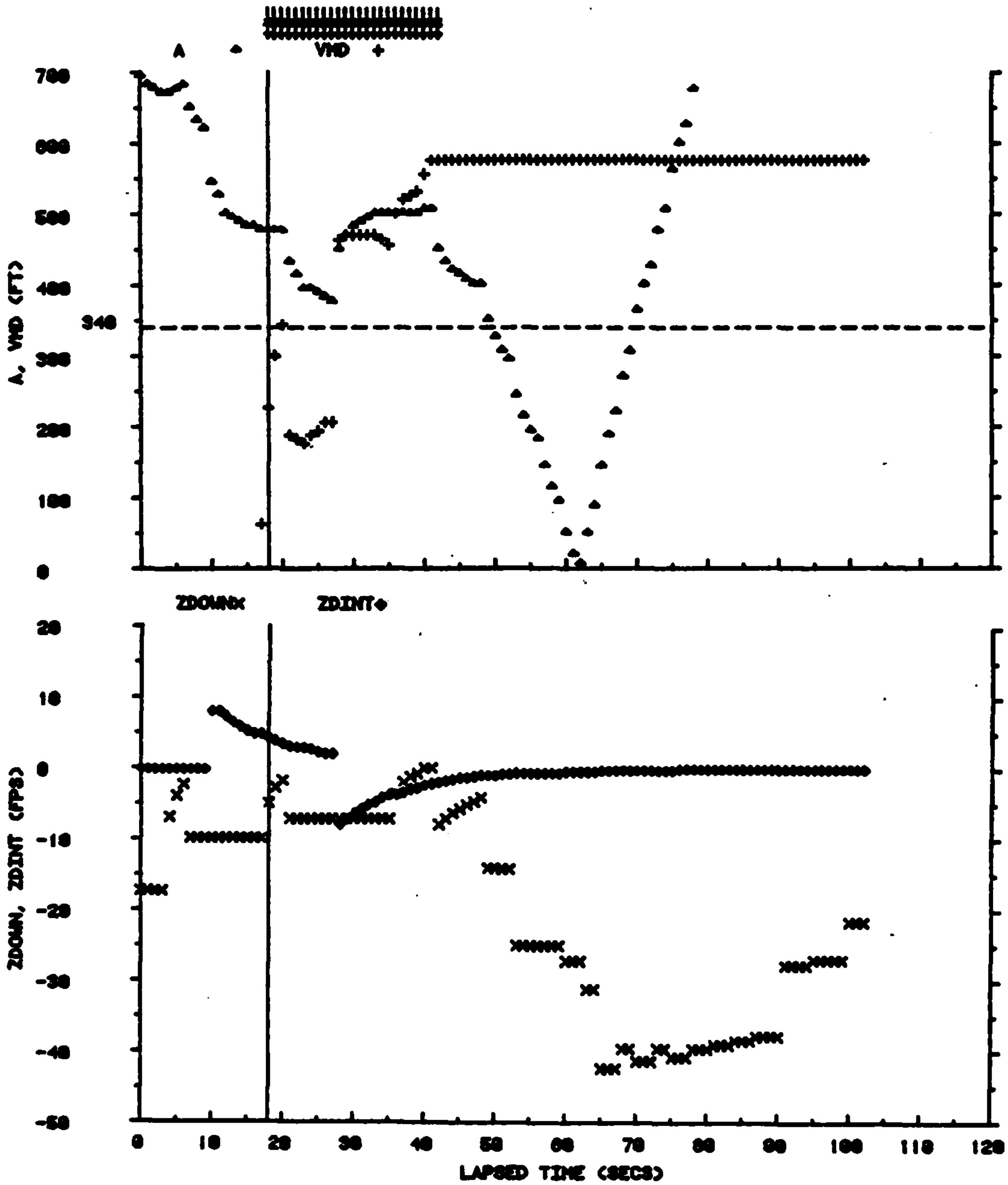


Figure 5-5. CASE 6: VERTICAL RATE AND ALTITUDE SEPARATION PLOTS

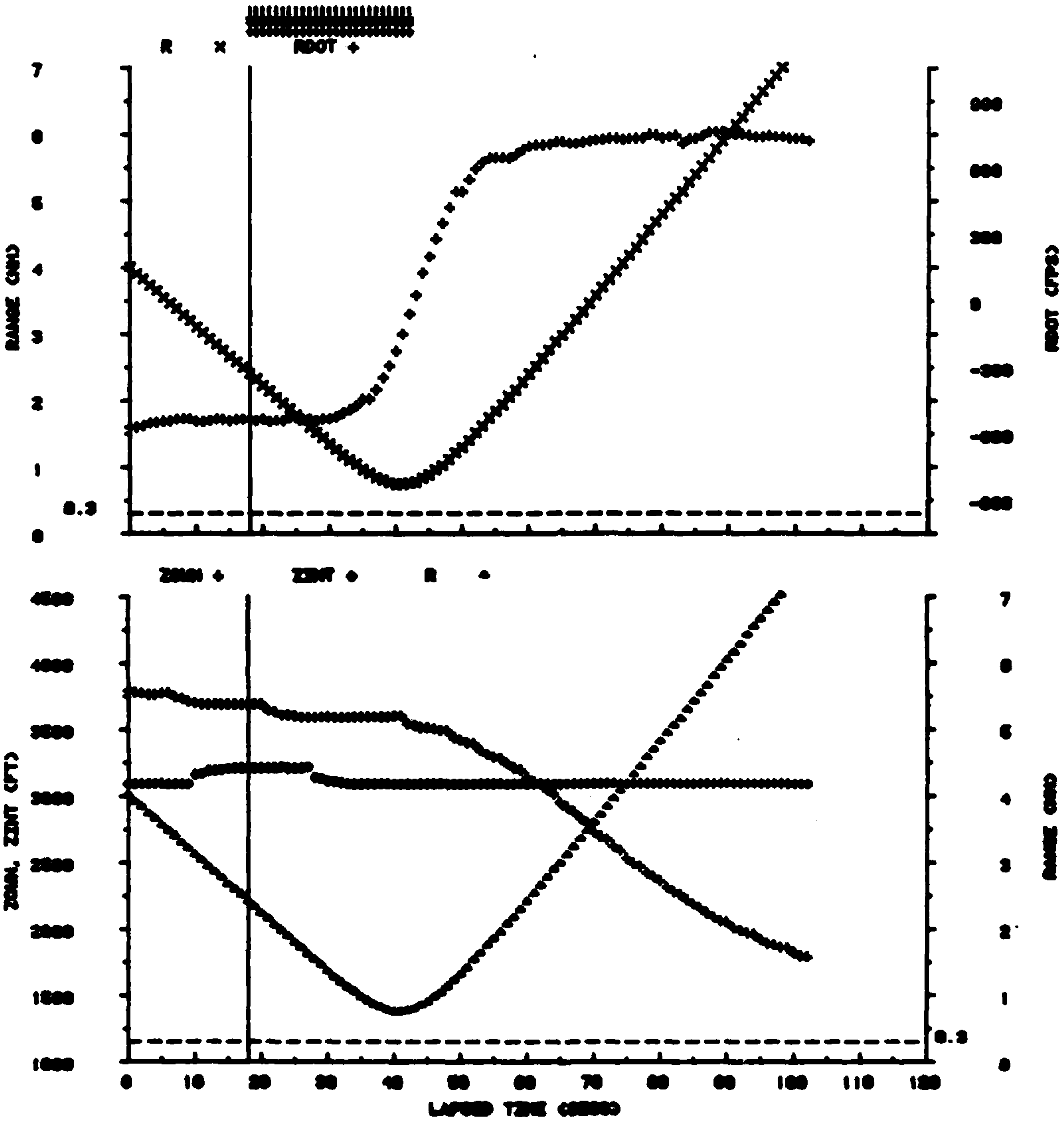


Figure 5-6. **CASE 6: RANGE, RANGE RATE, AND ALTITUDE PLOTS**

at 11 o'clock, 2 miles, 200 feet above the test aircraft. At the same time a "DON'T CLIMB" resolution advisory was given on the IVSI, followed five seconds later by a "DESCEND" advisory. The traffic display showed the intruder passing to the left of the test aircraft, which had been cleared to continue climbing after reporting the other traffic in sight.

This was a typical conflict situation, which was resolved by coordination between the two pilots and ATC. The TCAS display presented information that correlated with the actual event. The initial resolution was a corrective advisory and was correct for the situation. There was no prior traffic advisory in this case because the other aircraft made a turn that brought it into conflict with the test aircraft within the resolution advisory thresholds.

The recorded data confirmed the observer's account and showed that the horizontal range at point of altitude crossing was about 0.7 nautical mile.

Data plots for Case 7 are shown in Figures 5-7, 5-8 and 5-9.

5.4 CASE 11, EN-ROUTE ADVISORY

On the afternoon of 27 January 1982, the test aircraft operated as Piedmont Flight 55 between Norfolk, Virginia, and Charlotte, N.C., with an FAA observer aboard. Flight 55 was level at FL260 in visual conditions. The observer noticed a traffic advisory on the intruder at the 10 o'clock position, range greater than 4 miles, and 1,100 feet above the test aircraft. Subsequent traffic information showed the intruder crossing from left to right with the vertical separation decreasing from 1100 to 900 feet. No ATC advisory was given.

The FAA observer called the flight crew's attention to the intruder, but the flight crew did not maneuver to increase separation between the aircraft.

At a range of 4 miles, the TCAS gave a "DESCEND" advisory, followed by a "DON'T CLIMB," followed by a "DESCEND" and then followed by a "DON'T CLIMB."

The observer believed that the traffic information was valuable, especially since no ATC advisory was issued. The flight crew did not change altitude, but did request the TCAS minimum range and minimum altitude information from the observer. The observer and flight crew both believed that the "DESCEND" resolution advisory was unnecessary and in fact the flight crew did not maneuver the aircraft.

The recorded data confirm the observer record and show that the intruder passed 0.6 mile to the right front of the test aircraft with 900 feet of altitude separation.

Data plots for Case 11 are shown in Figures 5-10, 5-11 and 5-12.

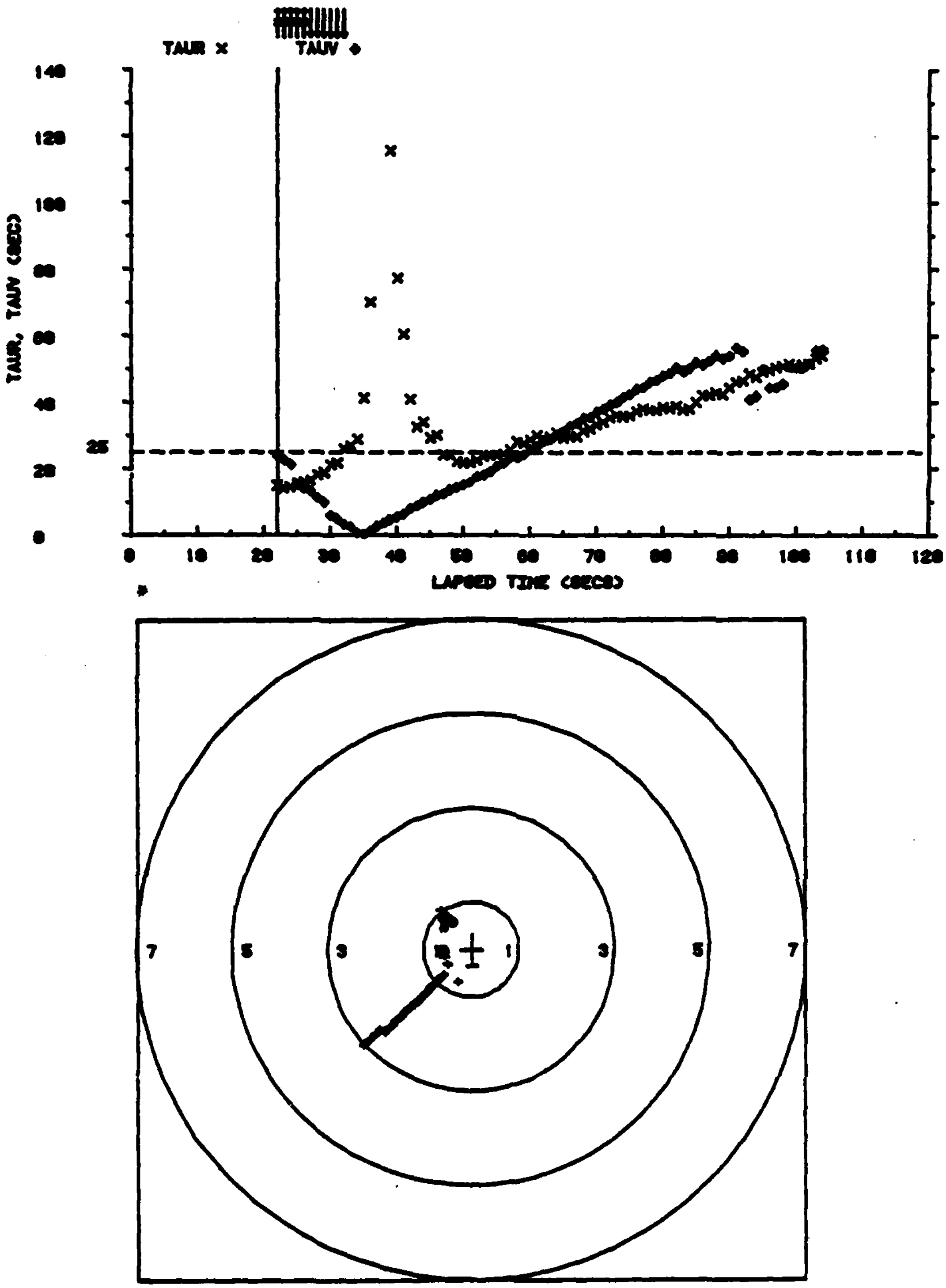


Figure 5-7. CASE 7: BEARING AND TAU PLOTS

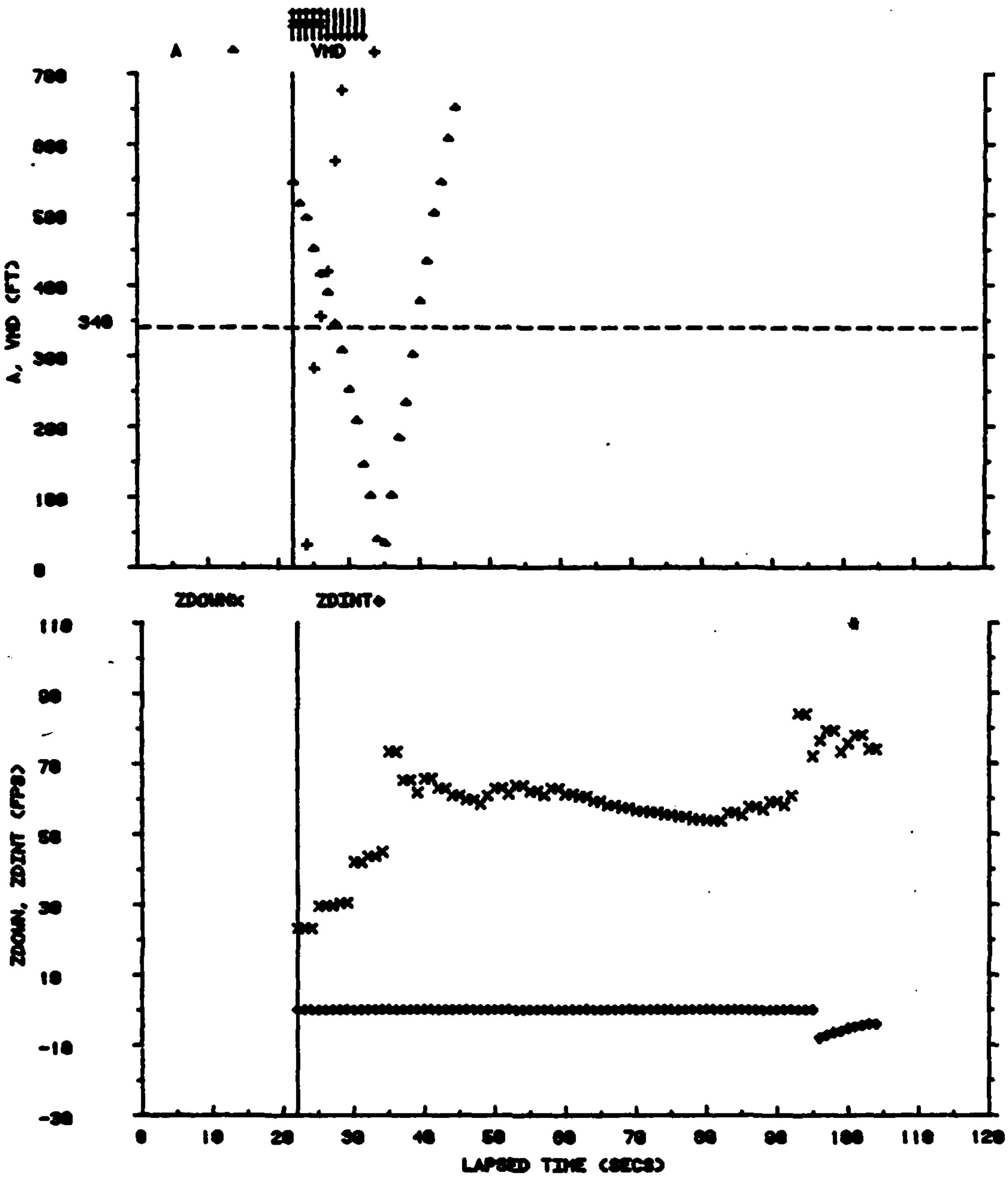


Figure 5-8. CASE 7: VERTICAL RATE AND ALTITUDE SEPARATION PLOTS

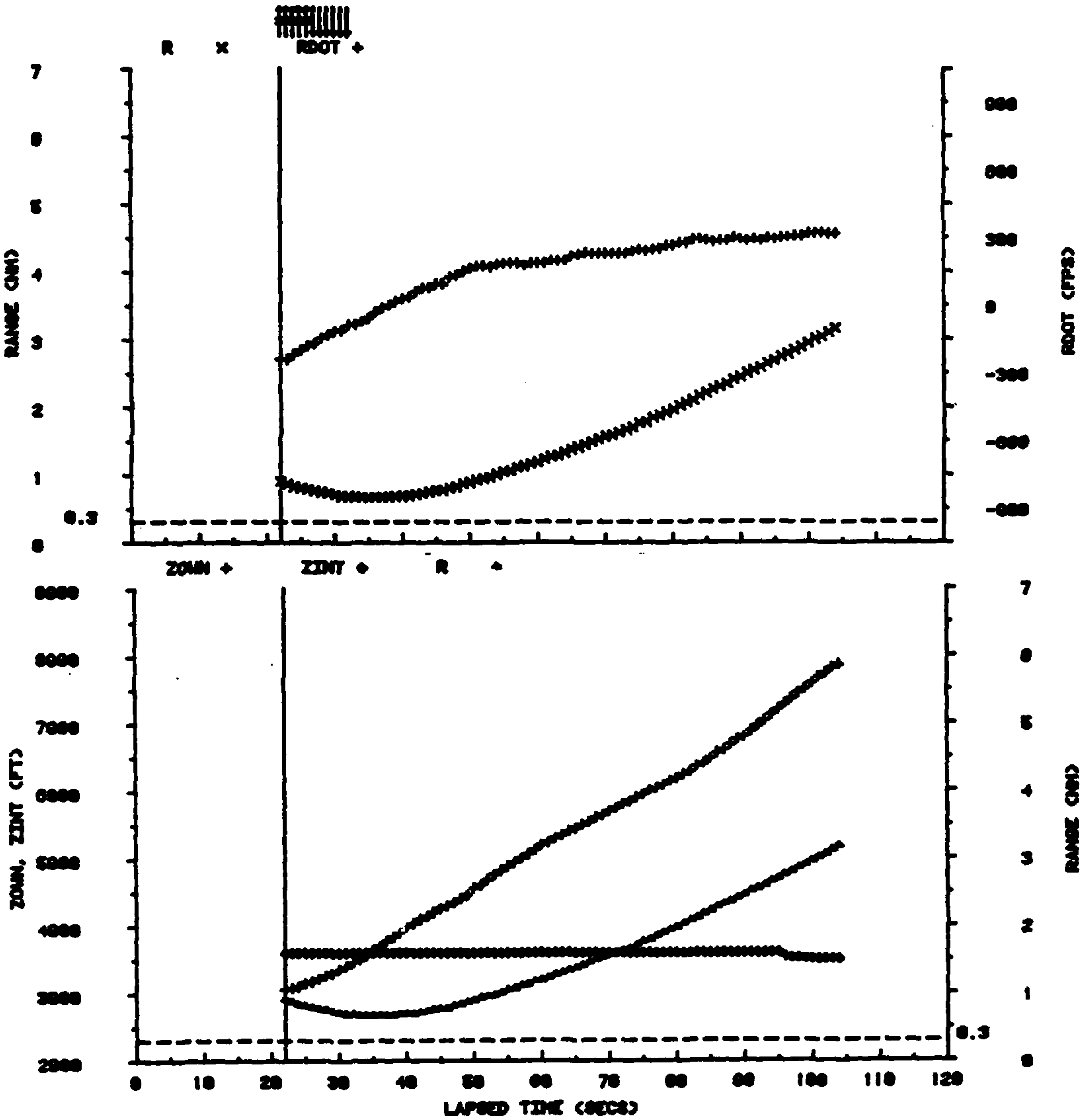


Figure 5-9. CASE 7: RANGE, RANGE RATE, AND ALTITUDE PLOTS

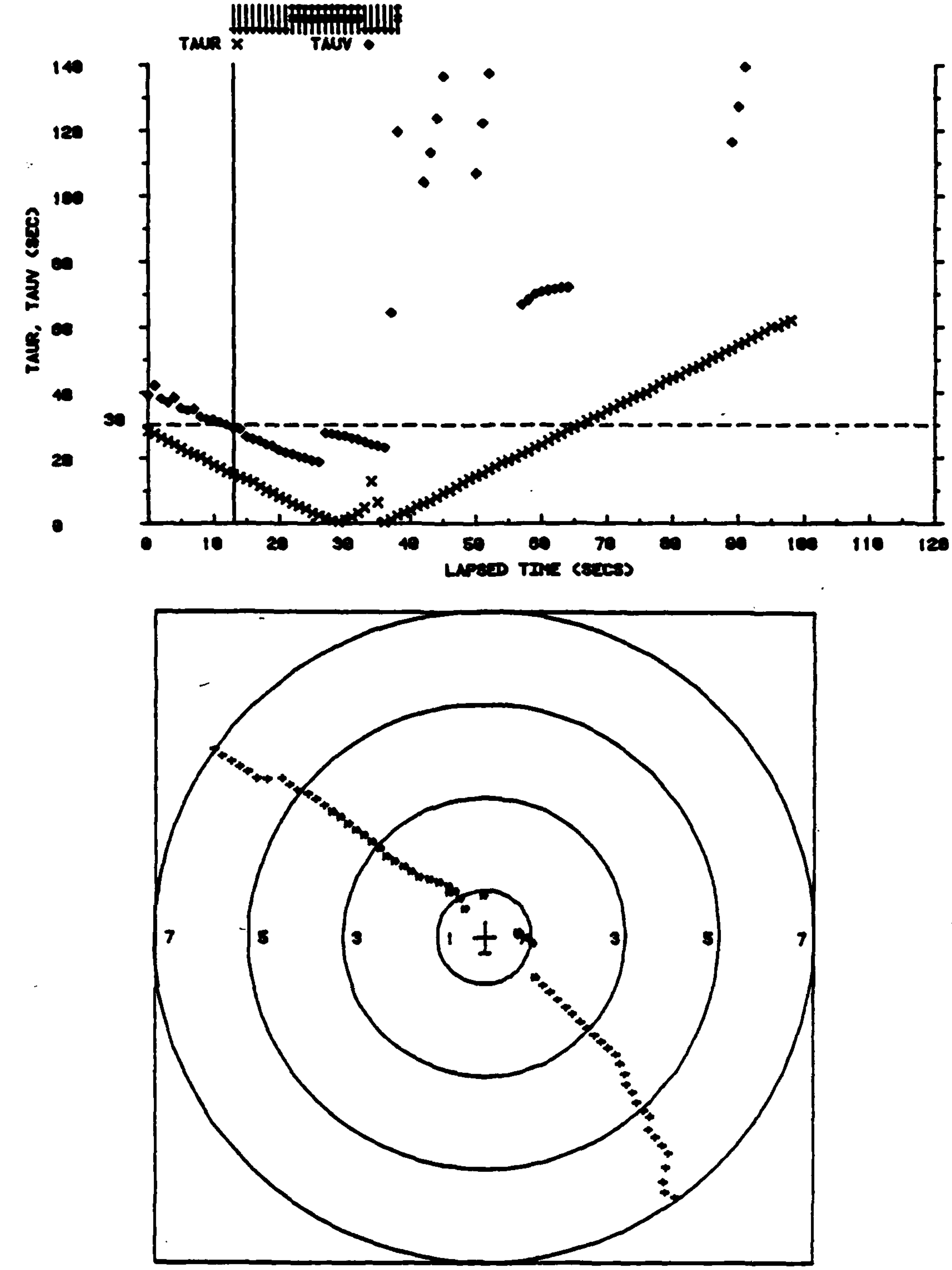


Figure 5-10. CASE 11: BEARING AND TAU PLOTS

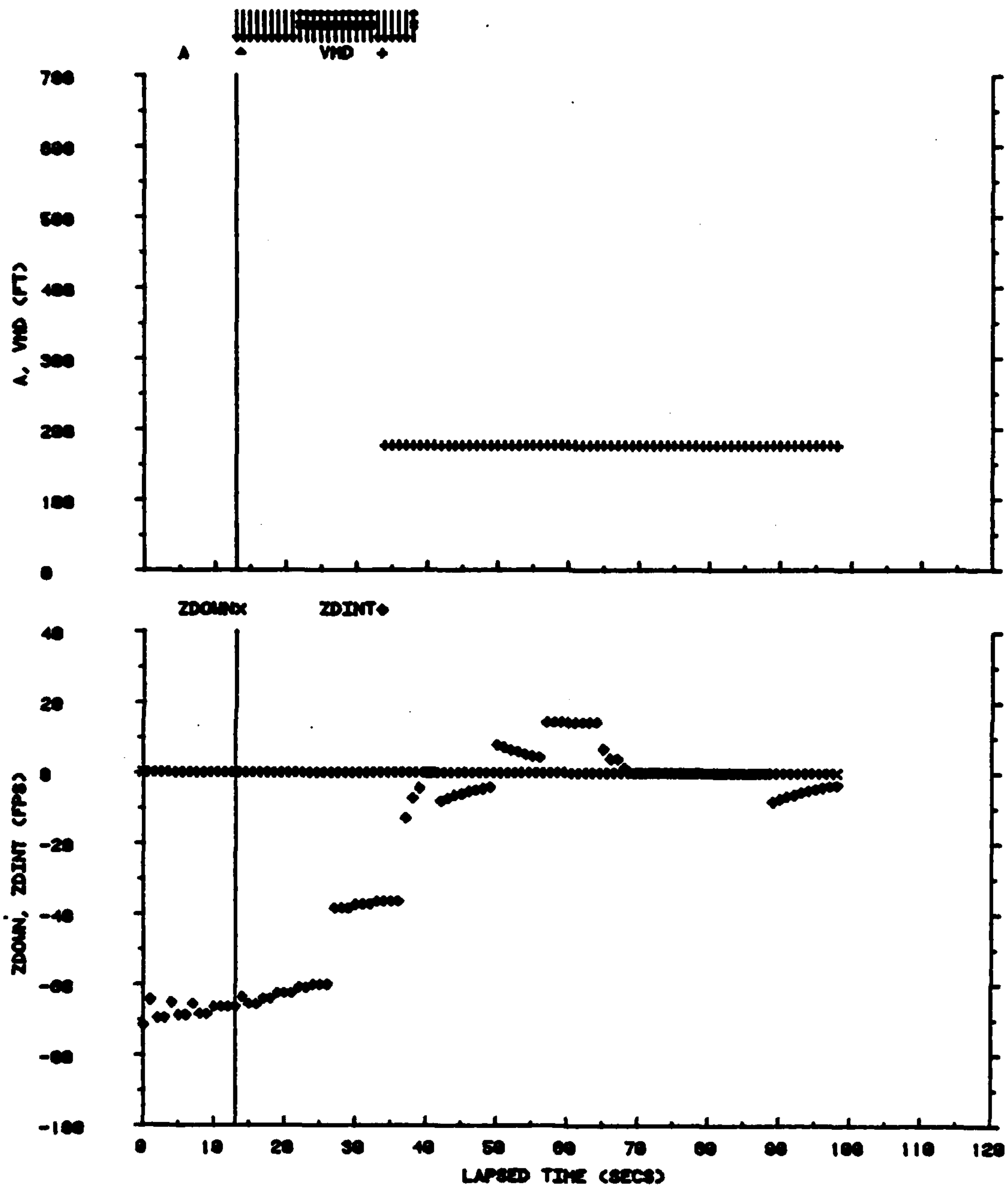


Figure 5-11. CASE 11: VERTICAL RATE AND ALTITUDE SEPARATION PLOTS

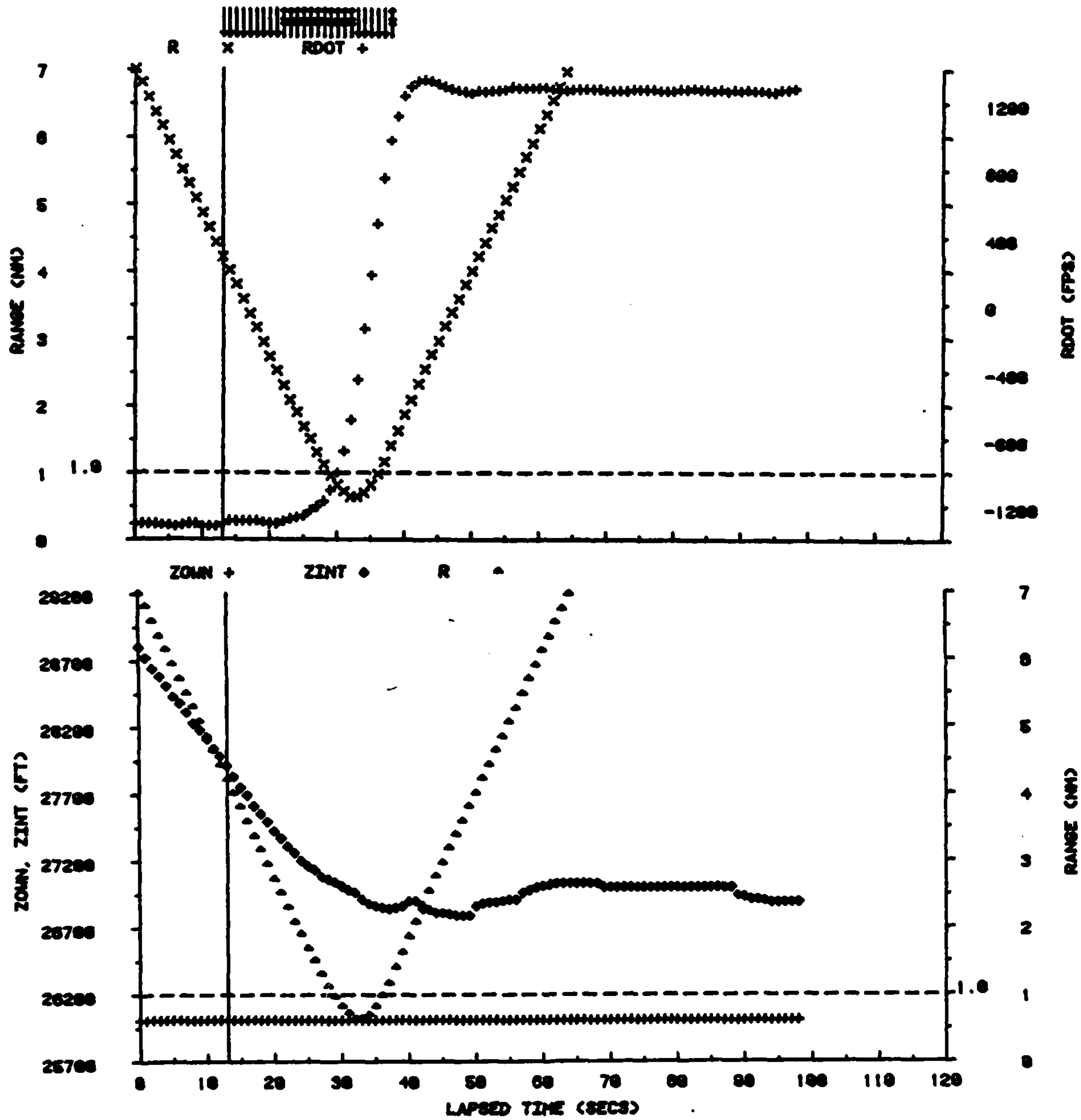


Figure 5-12. CASE 11: RANGE, RANGE RATE, AND ALTITUDE PLOTS

5.5 CASE 16, NORFOLK, VIRGINIA

On the afternoon of 20 February 1982, the test aircraft operated as Piedmont Flight 55 between Norfolk, Virginia, and Charlotte, N.C. An ARINC Research and an FAA observer were aboard. Six minutes after departing Norfolk Regional Airport, Flight 55 was approximately 20 miles west of Norfolk, flying westbound at 8000 feet. ATC advised of southbound traffic at 12 o'clock, 3 miles, at 8500 feet. The pilot saw a Cessna 172 almost simultaneously with the TCAS giving a traffic advisory on traffic at 1 o'clock, 3 miles, and 500 feet above the test aircraft. The pilot of Flight 55 reported the visual acquisition of the Cessna to ATC and was cleared to continue his climb, maintaining visual separation on the Cessna. The TCAS gave a "DON'T CLIMB" resolution advisory, but the pilot, who was unaware of the TCAS advisory, continued the climb.

The FAA observer believed the resolution was issued in sufficient time to comply and was the correct advisory.

Subsequent examination of the recorded data confirmed the observer account of the incident. The tape also revealed a failure in one of the receivers that caused the bearing data to be unreliable, as shown in Figure 5-13. All other types of data were unaffected, as shown in Figure 5-14 and 5-15.

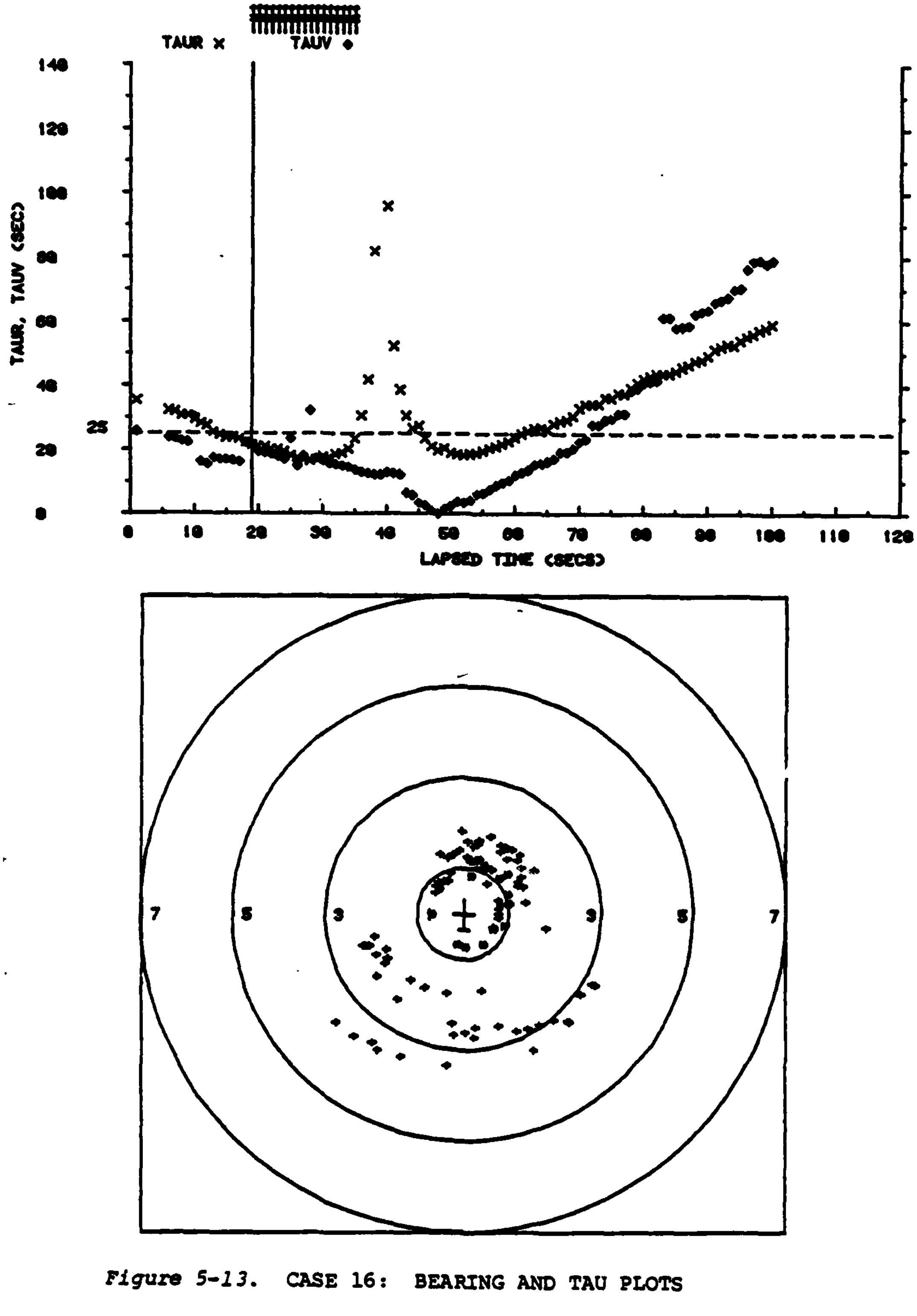


Figure 5-13. CASE 16: BEARING AND TAU PLOTS

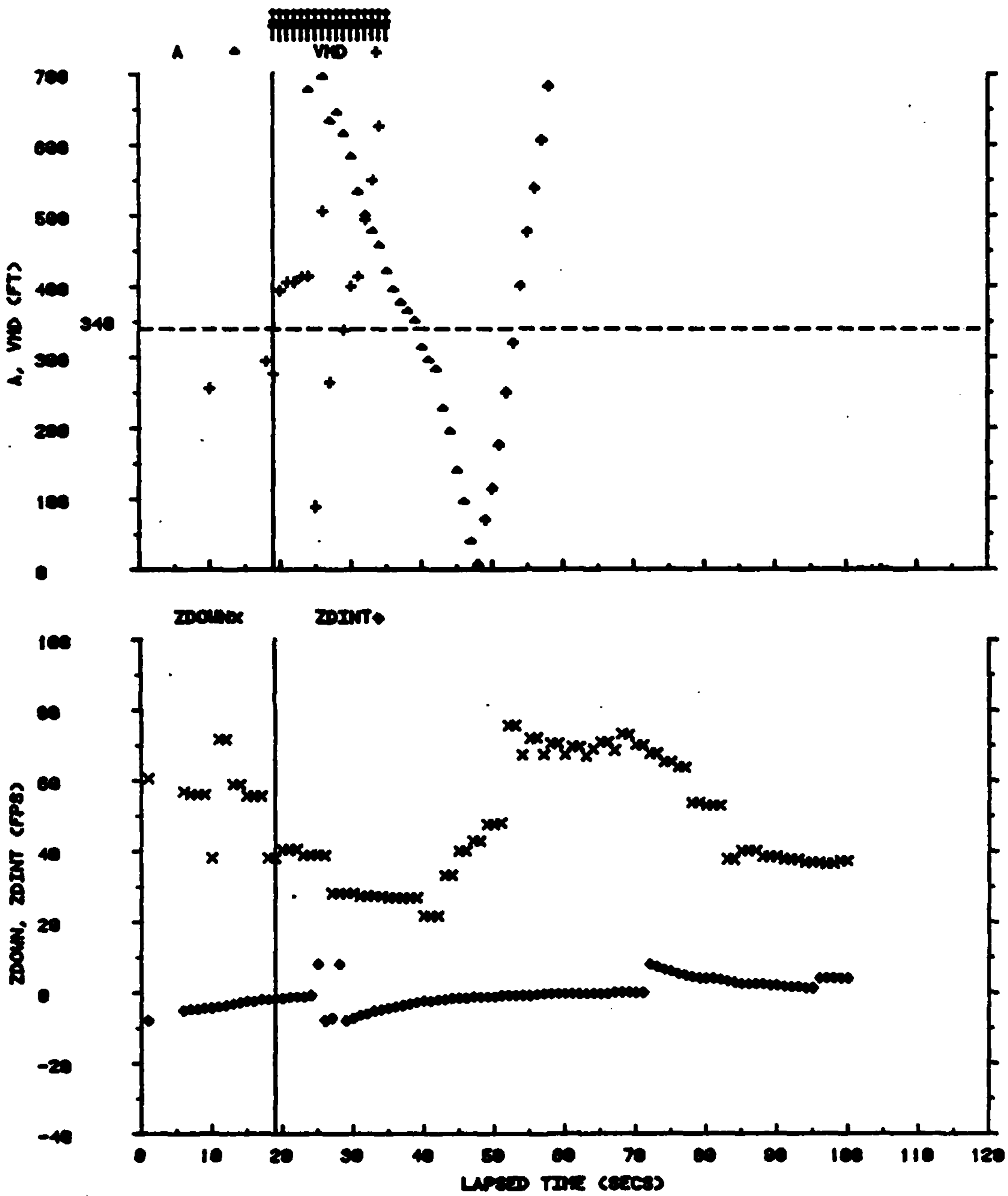


Figure 5-14. CASE 16: VERTICAL RATE AND ALTITUDE SEPARATION PLOTS

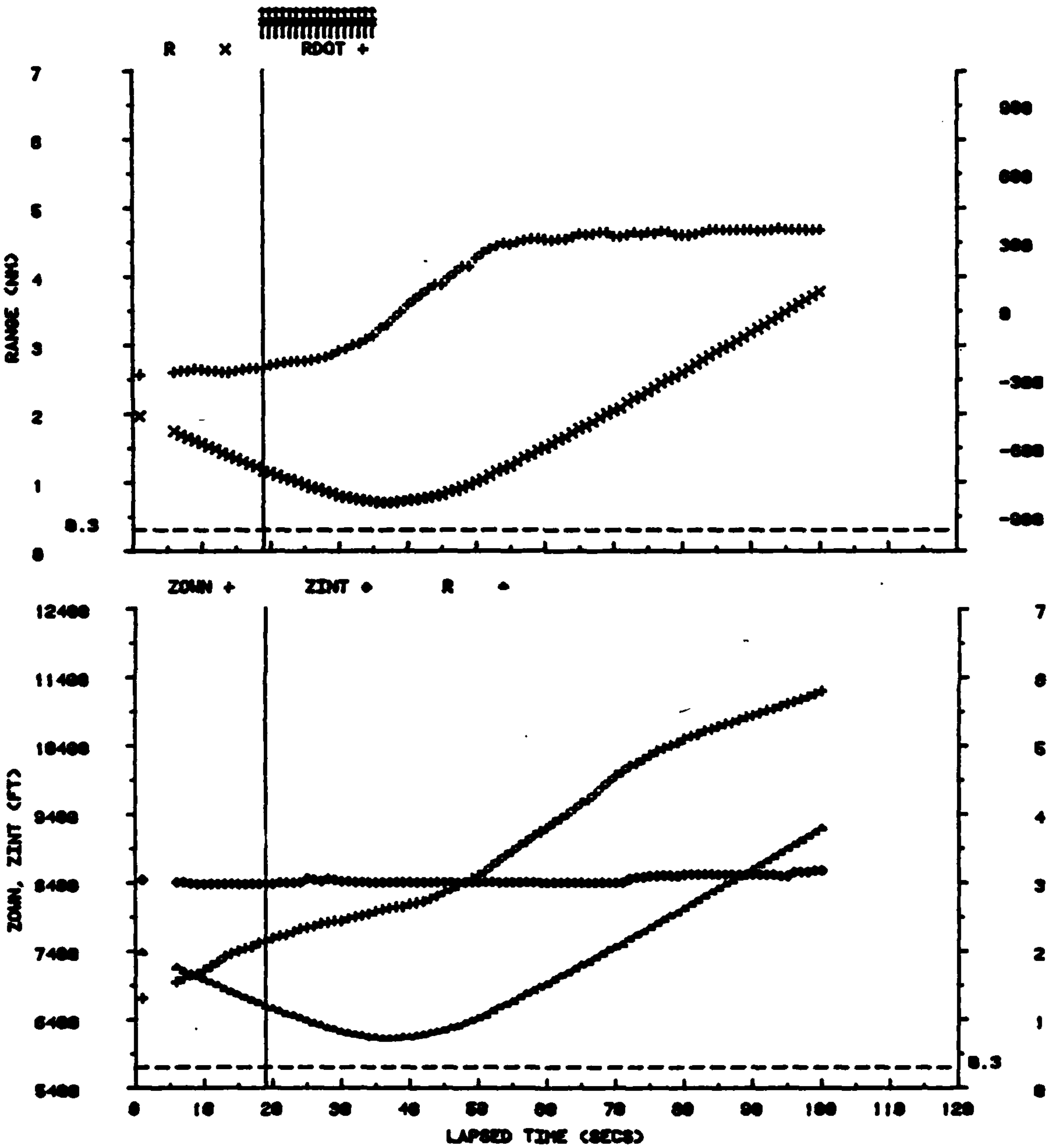


Figure 5-15. CASE 16: RANGE, RANGE RATE, AND ALTITUDE PLOTS

CHAPTER SIX

DATA ANALYSIS

The value of a collision avoidance system depends on its technical and operational performance. The operational evaluation was therefore designed to provide insight into both facets of the collision avoidance system: an objective evaluation of the technical performance of the system and a subjective evaluation of system operational performance. This chapter discusses the analysis of the data collected during the evaluation and presents results of the analysis in graphic, tabular, and narrative formats.

6.1 TYPES OF DATA

Data collection was discussed in detail in Chapter Four. The data fell into two categories: automatically recorded system performance data and descriptive or qualitative comments prepared by the flight observers. The automatically recorded data served as the basis for the majority of the statistical analysis, and the observer's comments served primarily as the basis for qualitative data analyses. In some cases the observer's comments provided a basis for examination of the quantitative data to ascertain the existence or magnitude of suspected problems.

The test observers' previous experience with collision avoidance systems ranged from extensive to none. The more experienced observers had developed some personal opinions on the utility of the various features of the collision avoidance system as installed on the test aircraft. The test observers made no significant changes in their established opinions as a result of their experience aboard the test aircraft. Therefore, we attempted to eliminate as much of the preconcived opinion data as possible without affecting the information provided by these experienced observers. Because the preestablished opinions represented two opposite evaluations of the features of the CAS, especially the value of proximity information, it appears that certain issues will remain unresolved and in fact may be dependent upon the operational procedures used by the individual operator.

The general quality of the automatically recorded data was very good, but minor equipment difficulties did affect the quality of some data. The major data deficiency noted was an intermittent failure to generate a date/time stamp for all data. When the recording system had no value

for the date/time word, it inserted a default value of zero. The data analysis used the system time developed by the processor to compute an elapsed time record of each incident. Although annoying, the absence of time-of-day data was not frequent and did not affect the development of event data such as tau values, event duration, sequence within an event, or sequence of events.

Shortly before the completion of the evaluation, one of the two systems developed a receiver sensitivity problem in two of the four receivers for the RF Processor unit. The result of this loss of sensitivity was the loss of accurate bearing information (but not range) for that system. All other data developed by the system were unaffected, so the data were included in all analyses except bearing analyses. Since the bearing of the threat aircraft was not used in the CAS resolution advisory calcualtions, the loss of bearing data did not affect the primary operational mission of the system.

No resolution advisory or traffic advisory cases were eliminated from analysis because of absence of either time or bearing data.

In addition to data relating to the aircraft involved in the potential conflict, the system generated data on its own behavior. These included word counts, lost data block counts, idle counts, error counts, CAS trace bit vectors, and bearing counts. Each of these data provided diagnostic indications of system operation, the path followed through the CAS logic, unused and available processor capacity, and the frequency of various error conditions.

6.2 TYPES OF ANALYSIS PERFORMED

The major thrust of this project was the collection of a performance data base while simultaneously observing the performance of the system in an operational environment. The flight crews were not involved in the experiment and did not respond to the advisories generated by the CAS. Therefore, there were no response data generated during the evaluation, and measurements of vertical and horizontal separations were unrelated to the performance of the CAS.

Data for each of the 32 incidents during which a resolution advisory was generated were analyzed to develop a precis of the incident. These summaries are contained in Appendix B. The block 1 (own aircraft data) and block 10 (intruder data) records and the data plots were correlated with observer comments, when available, to develop an understanding of the cause, sequence of events, and resolution of the incident.

The traffic advisories were similarly analyzed, but data plots were prepared only when there was a question about the printed data. The most frequent reason for preparation of data plots was the suspicion that a target track was dropped and restarted under a new track file number. While these incidents were observable in the data, there was no apparent drop in the displayed traffic advisories. When the two track files were

plotted on a single plot, the data provided a continuous record of the incident.

Individual case analyses, as indicated above, provided an understanding of the sequence of events during typical encounters. Accumulated data permitted a better characterization of typical encounters and development of distributions of encounter parameters. For resolution advisories these parameters included the following:

- Range and bearing at time of first advisory
- Bearing at time of advisory
- Range at time of advisory
- Relative altitude of time of advisory
- Distribution of advisories by performance level
- Distribution of advisories by own altitude at time of advisory
- Distribution of airspace densities at time of advisory
- Advisories by type of aircraft (when observed)
- Distribution of advisories by type
- Frequency of low altitude intruders
- Distribution of advisory types by compatibility with own flight path

Traffic advisories were analyzed to provide distributions of the following incident parameters:

- Relative bearing at time of first traffic advisory
- Range at time of first advisory
- Relative altitude at time of first advisory
- Distribution of advisories by altitude of intruder at time of advisory
- Distribution of advisories by perceived airspace density
- Number of traffic advisories that were precursors to resolution advisories

6.3 RESULTS

The operational evaluation covered 928.8 flight hours over the period from 12 November 1981 to 31 March 1982. During this time, 32 resolution advisories were recorded, and there were traffic advisories on 329 additional aircraft.

One trend developed early in the program and continued as a significant phenomenon throughout the evaluation. The desensitization technique used with the test systems did not adequately limit the effect of ground aircraft on the TCAS. Ground aircraft with operating transponders created a significant number of traffic advisories and seven resolution advisories. The effect of these advisories will be evident in each of the results discussed in this section.

The TCAS used a weight-on-wheels sensor, the radio altitude of the aircraft, and barometic altitude to change detection parameters at predefined altitudes. When the weight-on-wheels sensor sensed the aircraft as airborne, the TCAS started interrogating and tracking other aircraft and generated traffic advisories. Resolution advisories were inhibited until the aircraft was above 500 feet above ground level (AGL). Other performance level changes were made at 2,500 feet ALG, at 10,000 feet ALG and at FL290 to accommodate the higher speeds and altitude separation at those altitudes.

An operationally acceptable and technically workable desensitization technique to eliminate the unwanted advisories was developed and recommended to the FAA. The scheme, which will be implemented in the next test system, uses computed altitude difference between the TCAS aircraft and intruder aircraft and compares the difference to the altitude of the TCAS aircraft above the ground. When the values are approximately equal, the TCAS declares the intruder as on the ground and does not display a traffic advisory or resolution advisory to the flight crew. This technique requires continuous radar altitude information and operates only when the TCAS aircraft is less than 2500 feet above the ground.

This desensitization technique was recommended after evaluation of various flap, landing gear, and thrust combinations, and observation of the operation of preselected altitude trips to change TCAS sensitivity levels. None of those techniques appears to provide the required capability to consistently reject on-ground intruders.

6.3.1 Advisory Rates

Thirty-two encounters each generated one or more resolution advisories. A resolution advisory was generated (on an average) once every 29 hours. Seven of the resolution advisory incidents were caused by aircraft on the ground; thus there were 25 resolution advisory incidents involving airborne aircraft, or one each 37.2 flying hours. This represents the rate that can be expected in similar operations with a production collision avoidance system of the same design.

The incidence of traffic advisories was much more frequent. A total of 329 traffic advisories gave a rate of one traffic advisory per 2.82 flight hours. When the advisories generated by on-ground aircraft were excluded, we observed a traffic advisory rate of one each 5.13 hours. Total advisory counts are shown in Table 6-1 and advisory rates are shown in Table 6-2.

The continuing technical analysis by the FAA may expose hardware or logic problems not operationally discernable during this evaluation. Therefore, the encounter rates presented in this report include any doubtful cases and represents "worst case" performance.

6.3.2 Types of Intruder Aircraft

One of the information items recorded by the cockpit observer was the type (and model where known) of the aircraft that caused an advisory. The observers were able to identify the intruder aircraft as to type in all 8 resolution advisory cases that occurred while they were aboard the test aircraft. In 16 of the 50 traffic advisory events they were unable to identify the other aircraft. Figure 6-1 shows the distribution of intruders by type. The majority of the observed conflicts were with air carrier type aircraft, but only 2 of 31 advisories became resolution advisories. Conflicts with general aviation aircraft resulted in resolution advisories in more than half the cases (4 of 7).

The single largest category of intruder was the on-ground intruder. Such aircraft accounted for one-third of the observed resolution advisories and about 40 percent of the traffic advisories.

One difference that influenced on-ground advisory rates was noted between the two test aircraft. One aircraft used a weight-on-wheels sensor on the main gear to indicate an on-ground condition that stopped the TCAS from interrogating other aircraft. The second aircraft used a nose-gear sensor to determine an on-ground condition. It was found that the second aircraft more often established tracks on on-ground aircraft both during departure and landing. This difference is easily seen in the amount of data recorded after landing. The nose-gear ground sensor aircraft recorded a significantly longer period of on-runway data than was recorded by the main-gear sensor aircraft.

6.3.3 Altitude at Time of Advisory

More than 75 percent of the advisories occurred below 10,000 feet (MSL). The majority of the traffic advisories occurred when the test aircraft was below 1000 feet MLS and most of these low altitude advisories were caused by on-ground aircraft. The elevations of the airports included in the route structure of the test aircraft (Table 2-3) varied from near sea level at Newark, New Jersey, to almost 6000 feet at Denver, Colorado; however, the majority were below 1000 feet MSL. Most of the traffic advisories below 2000 feet MSL and especially those below 1000

Table 6-1. ADVISORY COUNTS

o Traffic Advisories		
Total	329	
Airborne Intruder	165	(50%)
On-Ground Intruder	148	(45%)
(Excluded from analysis)		
Undetermined	16	(5%)
o Resolution Advisories		
Total	32	
Airborne Intruder	25	(78%)
On-Ground Intruder	7	(22%)

Table 6-2. ADVISORY RATES

o Traffic Advisories	
All Advisories	1 per 2.82 hours
Airborne Aircraft	1 per 5.13 hours
o Resolution Advisories	
All Advisories	1 per 29.03 hours
Airborne Aircraft	1 per 37.15 hours

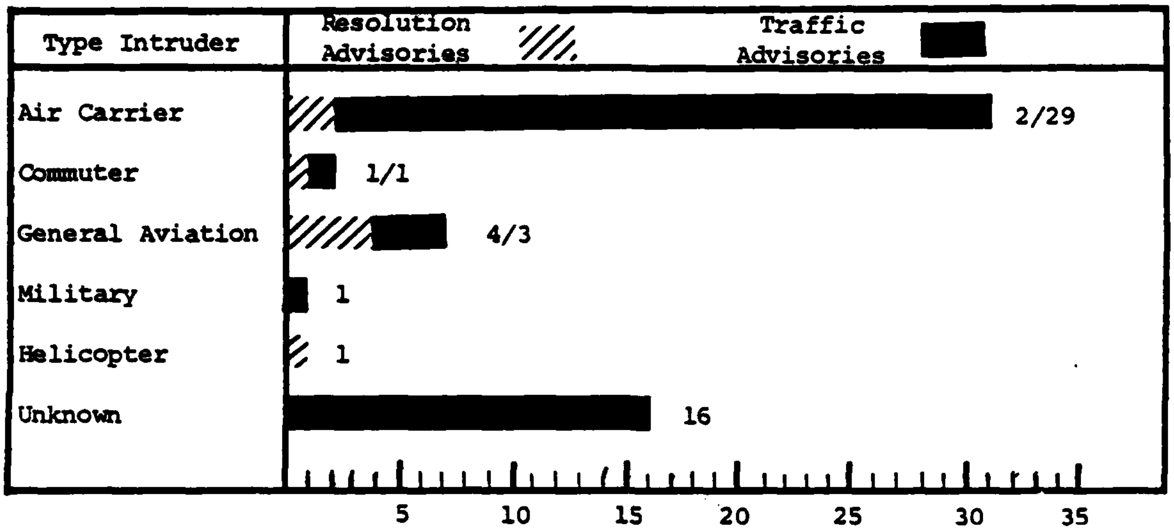


Figure 6-1. TYPE OF INTRUDER (OBSERVED ADVISORIES ONLY)

feet MSL were most likely caused by on-ground aircraft. The distribution of advisories at time of first advisory is shown in Figure 6-2.

6.3.4 <u>Vertical Separation at Time of Advisory</u>

Figure 6-3 presents a picture of the vertical separation of the aircraft at time of initial advisory. This chart refers only to traffic advisories since resolutions are almost always preceded by a traffic advisory.

Normal separation between aircraft in level flight is 500 feet vertically when crossing and operating under visual flight rules (VFR). The minimum vertical separation between two aircraft operating under instrument flight rules (IFR) is 1000 feet.* These clearances apply to level flight only, and horizontal separation is used between climbing and descending aircraft. Pilots may agree to accept less than standard separation under VFR procedures. Less than 10 percent of the traffic advisories were generated by aircraft more than 2000 feet above or below the test aircraft; almost 60 percent of the traffic advisories were generated by aircraft within 1000 feet of the test aircraft. These values indicate that the system seldom generated traffic advisories on aircraft that had satisfactory vertical separation. Analysis of a number of individual incidents show that the relative altitude at the time of first alert had a correlation with the vertical rates of the aircraft: the greater the altitude difference, the greater the vertical rate of the aircraft involved. Most often it was the vertical rate of the test aircraft that caused the traffic advisory.

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* Federal Aviation Regulations, Parts 91.109 and 91.121

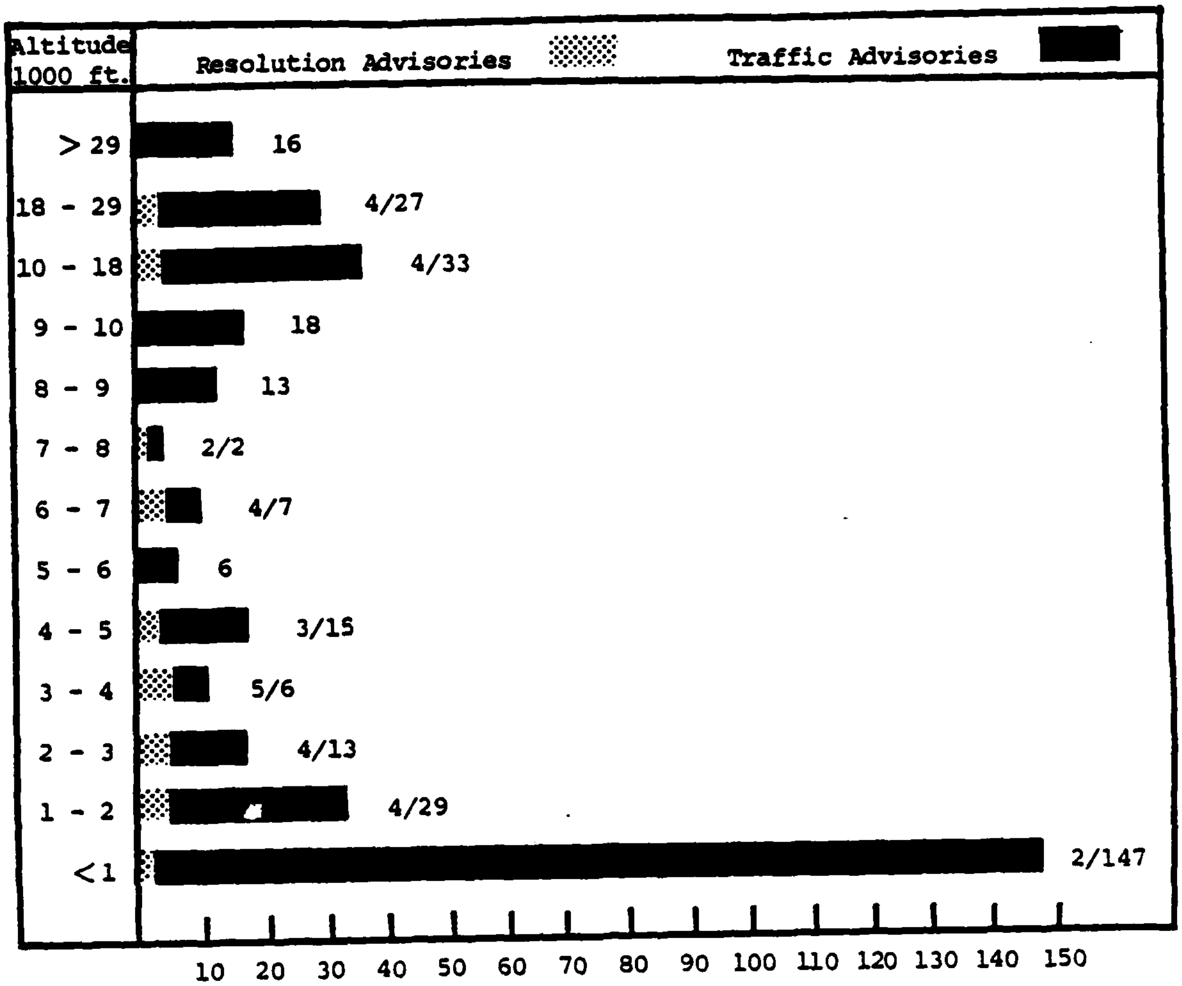

Figure 6-2. ALTITUDE OF OWN AIRCRAFT AT TIME OF FIRST ADVISORY

6.3.5 Range at Time of First Advisory

Most of the traffic advisories for airborne aircraft (52 percent) were given when the intruder aircraft was at a range of less than four miles. Resolution advisories were most often (67 percent) generated at ranges of less than 2.5 miles. Of the advisories generated at ranges of less than four miles, the average range at first resolution advisory was 1.62 miles. As expected, traffic advisories were first generated at greater ranges than first resolution advisories. On average, a first traffic advisory was generated at a range 0.415 mile greater than a first resolution advisory. Seven of the 28 resolution advisories with sufficient data for analysis were generated by on-ground aircraft. Figure 6-4 shows range at first advisory.

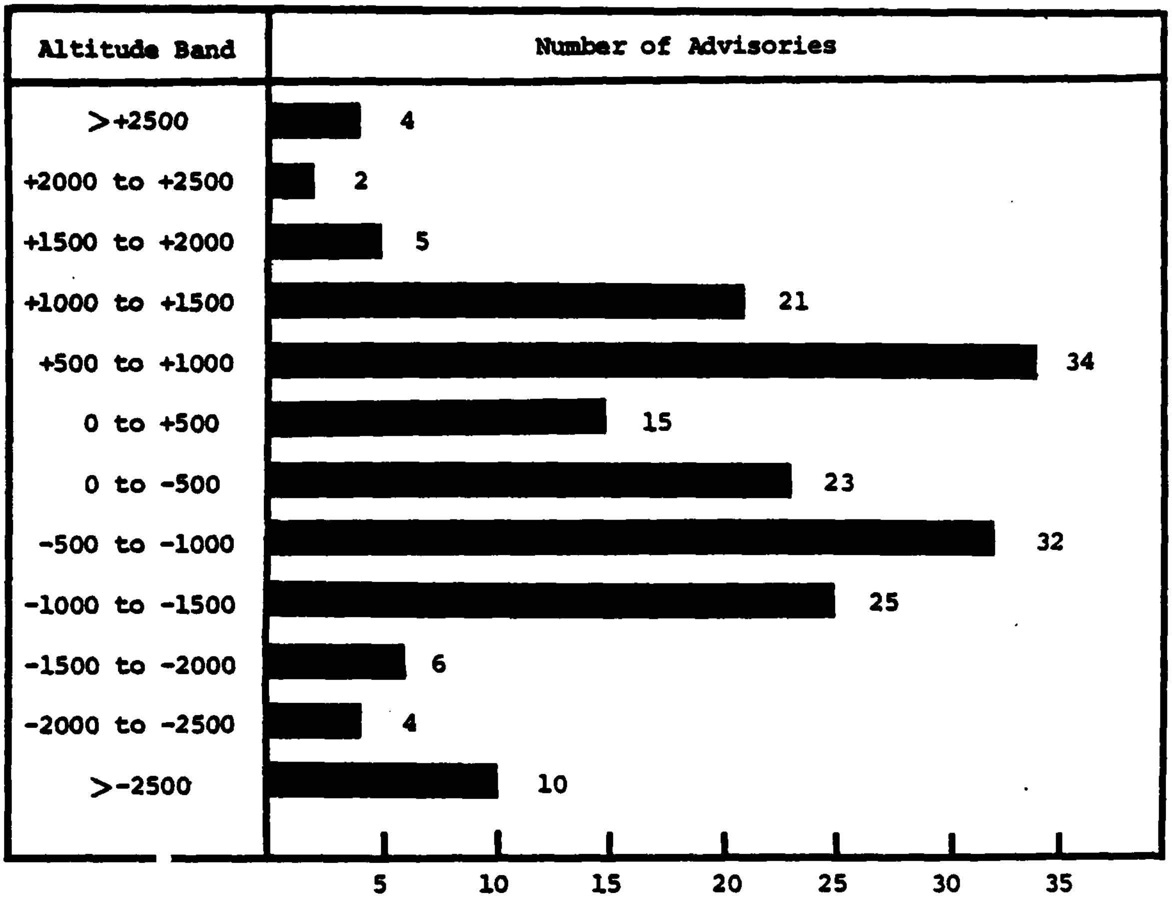

Figure 6-3. TRAFFIC ADVISORIES BY RELATIVE ALTITUDE (AIRBORNE TRAFFIC ONLY)

6.3.6 Relative Bearing of Threat Aircraft at Time of Advisory

The bearing data recorded during the operational evaluation confirmed the intuitive expectation that the majority of the conflicts would develop within a bearing of ±90° from the test aircraft. Figure 6-5 shows the frequency of both traffic advisories (TA) and resolution advisories (RA) by relative bearing octant. Slightly more than two-thirds (67.9 percent) of the traffic advisories were generated by aircraft with a ±90° bearing. Most of the resolution advisories (80.9 percent) were generated by aircraft forward of the test aircraft, and no resolution advisories were recorded within the aft quadrant.

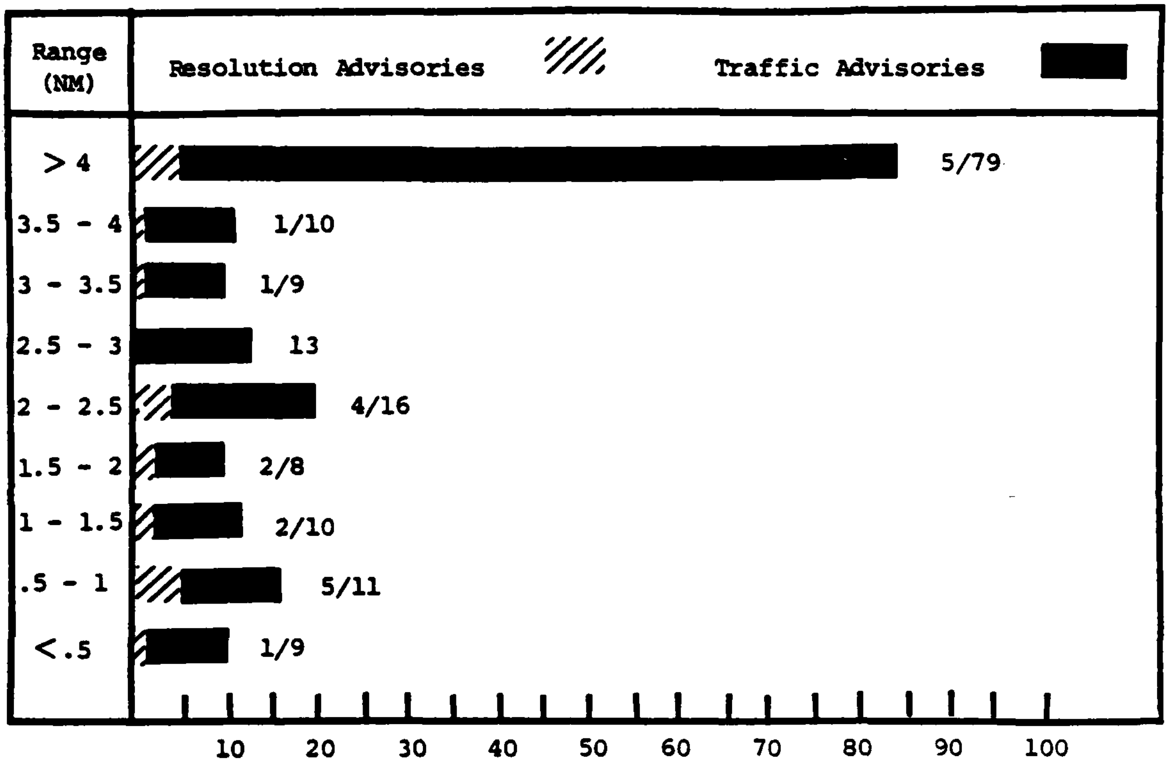

Figure 6-4. ADVISORIES BY RANGE
(AIRBORNE AIRCRAFT)

The number of relative bearing measurements was somewhat limited as a result of a partial failure of a receiver in one of the avionic systems near the end of the data collection period. Successful operation of the TCAS requires only range and altitude data. Therefore, the failure in this receiver did not affect any other data item except relative bearing. Since all other data were normal, it was decided to complete the test without repairing the failed receiver.

6.3.7 Types of Resolution Advisories

Twenty-five encounters were observed or recorded during the operational flight test. Several of those incidents resulted in multiple advisories, primarily because the flight crew was unaware of the advisory and thus could not respond. The 25 conflict incidents consequently resulted in a total of 43 different resolution advisories. These data are shown in Figure 6-6.

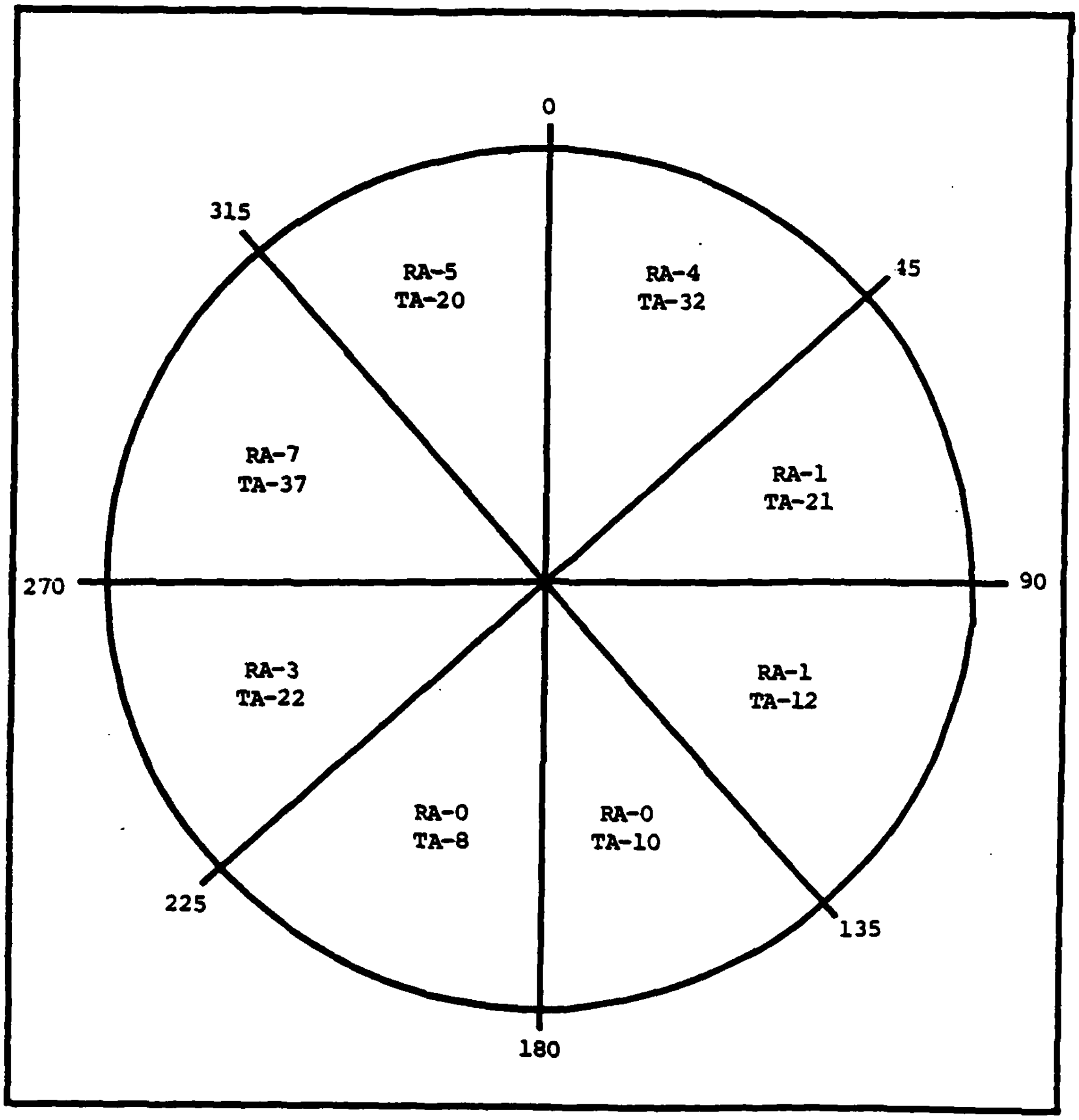

Figure 6-5. ADVISORIES BY INITIAL BEARING (AIRBORNE WITH BEARING DATA)

The twenty-five resolution advisories were generated by airborne aircraft. None of the initial advisories were minimum rate advisories. There were nine limit vertical speed advisories, ten negative advisories, and six positive advisories. For the airborne intruders, the majority of the advisories (14) were u-sense advisories; there were eleven down-sense advisories.

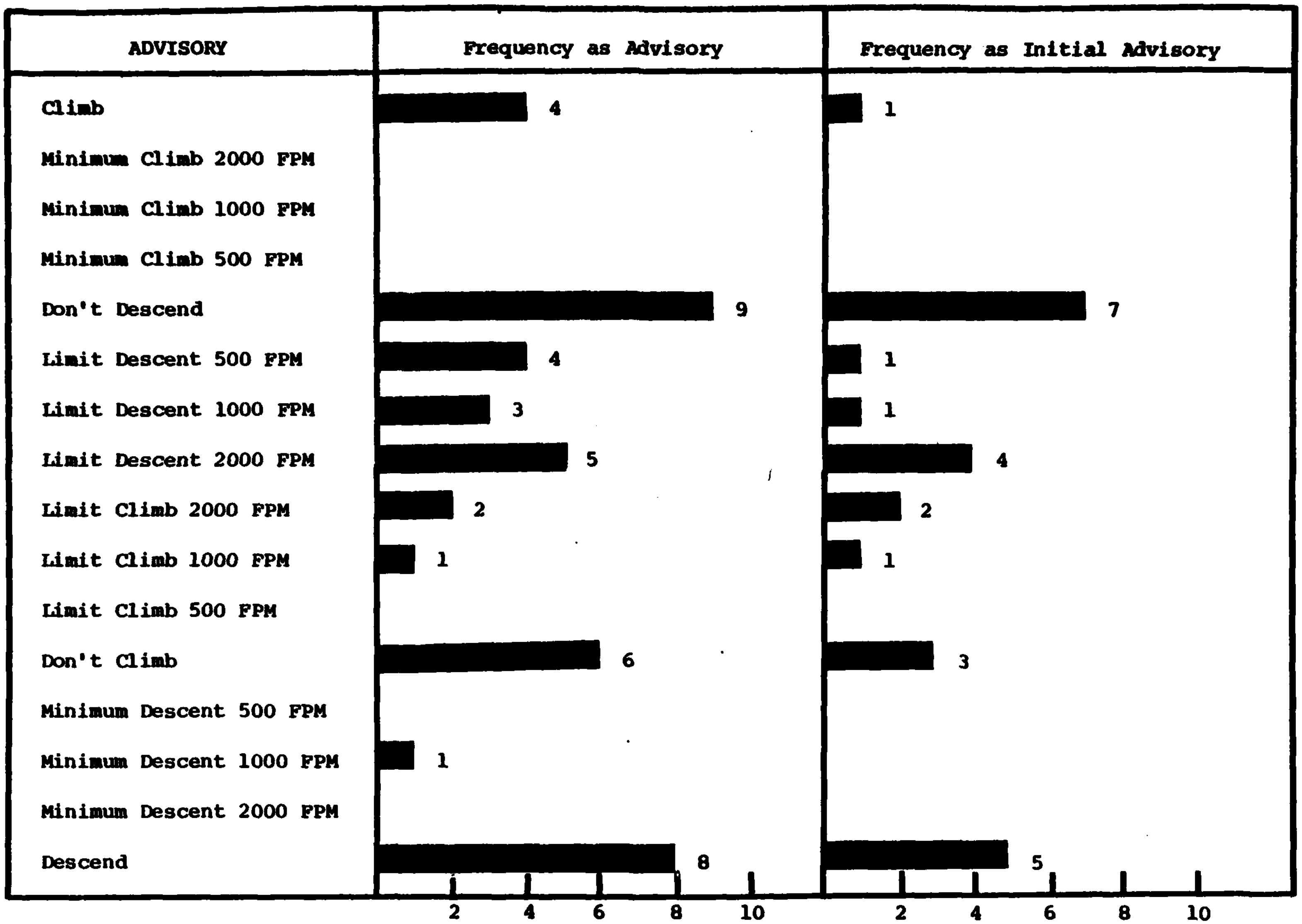

Figure 6-6. RESOLUTION ADVISORY FREQUENCIES
(AIRBORNE AIRCRAFT)

6.3.8 Effect of Resolution Advisories on Own Flight Path

The effect of a resolution advisory on the flight crew depends on the flight crew action necessary to comply with the advisory. Resolution advisories may be classified as "corrective" or "preventive". These terms are defined as follows:

> Corrective Advisory - A resolution advisory that recommends a change of current vertical rate, as for example, a "DON'T CLIMB" when the aircraft is climbing.
>
> Preventive Advisory - A resolution advisory that is not "corrective".

The classification of a resolution advisory as "corrective" or "preventive" depends on the current vertical rate of the aircraft and the immediate intentions of the flight crew.

Figure 6-7 gives a matrix of advisory/flight path combinations, with the number of times each combination was encountered during the TCAS operational evaluation. After excluding advisories against on-ground aircraft, this evaluation found eight incidents of corrective advisories, ten incidents of preventive advisories, and seven incidents of uncertain classification, which depended on the vertical component rate of the aircraft flight path.

During the operational evaluation, there were eight corrective resolution advisories, absolutely requiring a change in flight path to comply with the advisory. This equates to a rate of one corrective advisory each 116 flight hours. On the assumption that half of the uncertain advisories would also be corrective, the overall expected rate for corrective advisories is one each 80.7 hours. Examining the worst case; i.e., where all the uncertain advisories proved to be corrective, the expected corrective advisory rate is one per 61.9 flight hours. On the basis of a total of 543,155 flight hours per month for air carrier turbojet aircraft* (18,105 flight hours per day), there should be an average of 156 (18105 ÷ 116) to 292 (18105 ÷ 61.9) corrective advisories generated within the NAS each day. An individual air carrier turbojet flight crew might expect to encounter one or fewer corrective advisories per month.

6.3.9 Duration of Advisories

Time data were recorded for 28 of the 32 resolution advisories experienced during the operational evaluation. Time lines on these incidents are shown in Figure 6-8. That figure indexes the time lines to the start of the first resolution advisory, indicated by the solid line extending down the approximate center of the figure. Time lines

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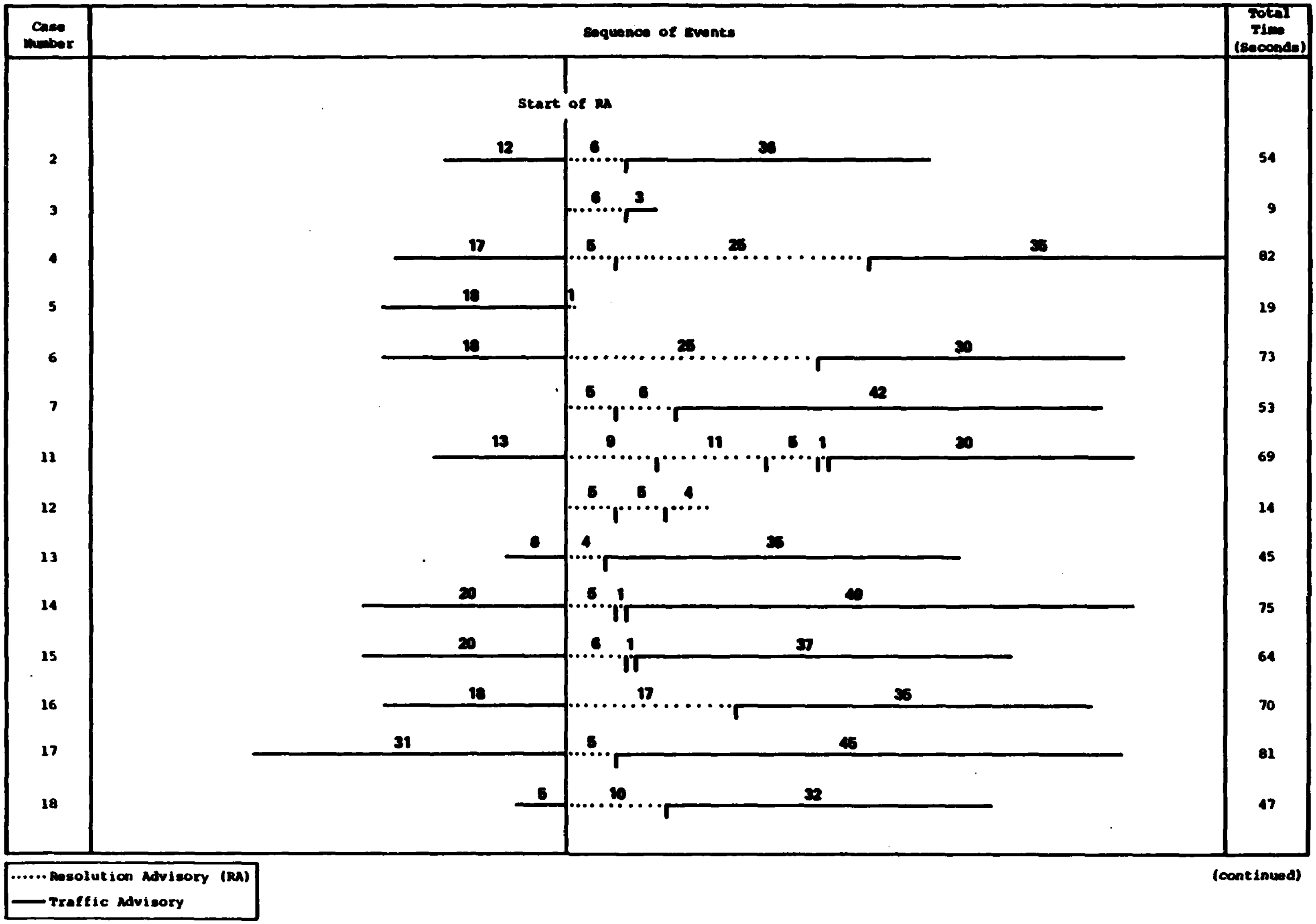
* Aircraft Utilization and Propulsion Reliability Report, RIS:AC 8320-1 FAA Flight Standards National Field Office, June 1982, Data for April 1982.

TYPE RA	POSITIVE	VSM	NEGATIVE	VERTICAL SPEED LIMIT		NEGATIVE	VSM	POSITIVE
ADVISORY / FLIGHT PATH	CLIMB	MINIMUM CLIMB	DON'T DESCEND	LIMIT DESCENT RATE	LIMIT CLIMB RATE	DON'T CLIMB	MINIMUM DESCENT RATE	DESCEND
INCREASING CLIMB RATE			1		1			
STEADY CLIMB								
DECREASING CLIMB RATE				1	1	2		
LEVEL	1		2		1			4
DECREASING DESCENT RATE			2	3		1		
STEADY DESCENT			2					
INCREASING DESCENT RATE			1	1				1

Type Advisory: Corrective / Preventive / Uncertain

Figure 6-7. RESOLUTION ADVISORIES COMPARED TO OWN FLIGHT PATH (AIRBORNE AIRCRAFT)



(continued)

Figure 6-8. ADVISORY TIME LINES

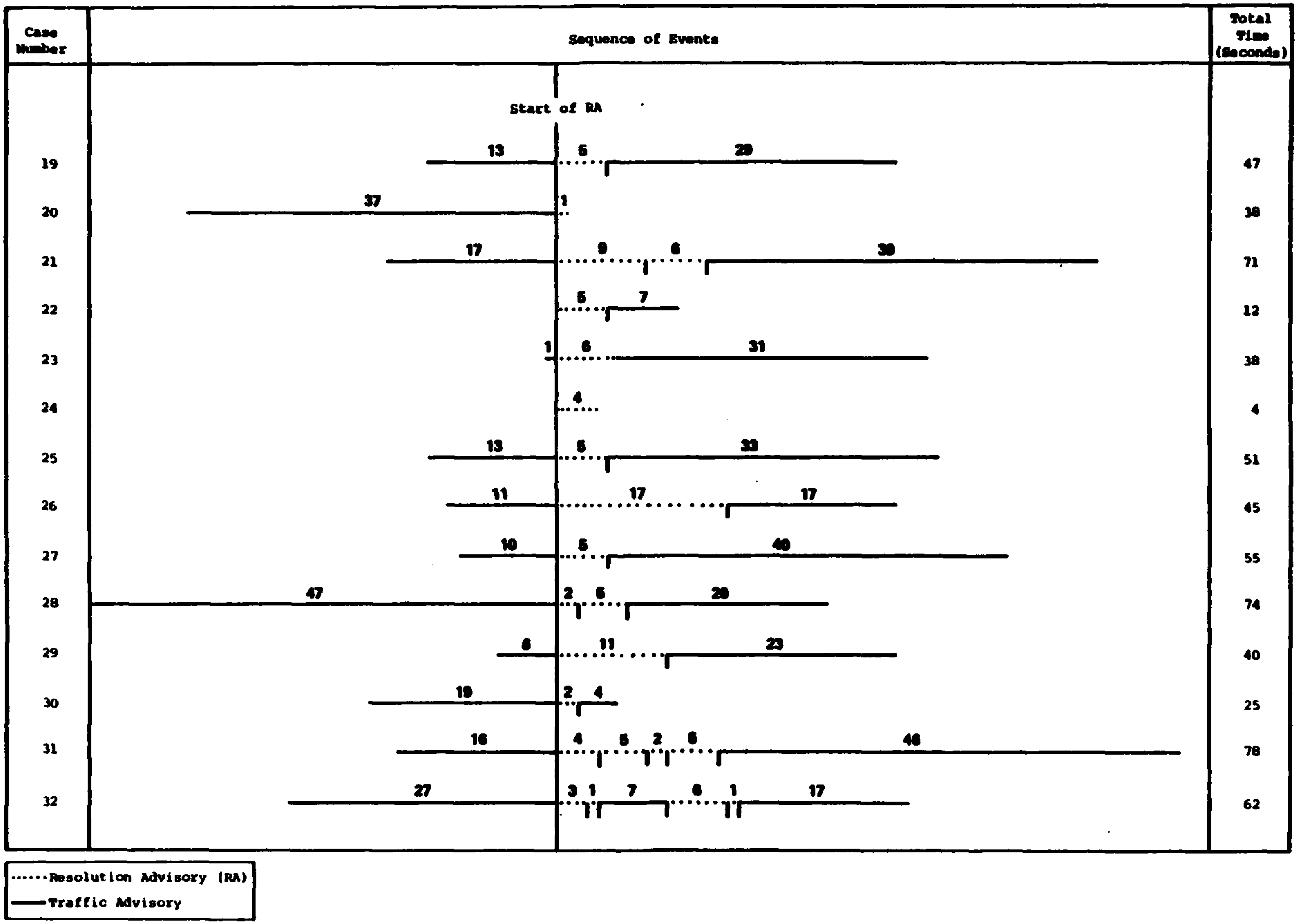


Figure 6-8. (continued)

to the left of the index show precursor traffic advisories. The resolution advisories and changes in advisory are shown inside short indexes, and post-RA traffic-display time is shown at the last part of the time line.

Maximum precursor traffic advisory time was 47 seconds, in Case 28. Minimum precursor time was 0, in Cases 3, 7, 12, 22, and 24. The average precursor traffic advisory was 14.46 seconds, with a standard deviation of 12.75 seconds.

The average resolution advisory series lasted 9.93 seconds, with a standard deviation of 7.61 seconds. The maximum duration observed was 30 seconds (Case 4) and the minimum was 1 second (Cases 5 and 20).

The average post-RA traffic advisory persisted for 25.54 seconds, with a standard deviation of 15.87 seconds. The maximum post-RA traffic advisory was 49 seconds (Case 14) and the minimum was 0 seconds (Cases 5, 12, 20, and 24).

The total incident duration, from start of first advisory to end of last advisory averaged 49.46 seconds, with a standard deviation of 23.98 seconds. The minimum incident time observed was 4 seconds (Case 24) and the maximum was 82 seconds (Case 4).

Cases with no precursor TA and cases with no post-RA traffic advisory were observed. Of the five cases with no TA precursor (Cases 3, 7, 12, 22, and 24), three involved the test aircraft or the intruder aircraft at ground level. In Case 7, the TCAS criteria were met when both aircraft maneuvered with proper separation in visual conditions and with the other aircraft in sight. One case (Case 12) involved a simultaneous approach to parallel runways. Case 28 was unobserved, but subsequent traffic advisory data on the same tape indicated that the test aircraft was maneuvering during the approach phase and following the other aircraft. The same circumstances also appear to have caused Case 23.

In Case 18, bearing data show that one or both aircraft were turning during the incident, which appears to have occurred during descent from en-route altitude into the terminal area.

Case 29 occurred when the test aircraft made a fairly high-rate en-route descent and leveled off 100 feet above the other aircraft.

All other resolution advisory cases involved TA precursors of 10 seconds or more.

All of the resolution advisories occurred from normal, expected, and unremarkable traffic situations. Most RA situations occurred in VMC, and most TCAS-derived resolution advisories were compatible with the maneuvers subsequently performed by the test aircraft.

Selected resolution advisory cases are discussed in Chapter Five.

6.4 OBSERVER COMMENTS

While not all data flights carried observers, there were sufficient observed flights to provide some insight into the compatibility of the TCAS with normal air carrier operation. Some observers rode the aircraft a full day without seeing either a traffic advisory or resolution advisory; a few observers never saw a resolution advisory. As a group, however, the observers believed that they could comment on the performance of the system.

The observers were unanimous in the conclusion that the TCAS provided a useful service. They believed that the TCAS maneuvers were compatible with air carrier operations, and compliance with the maneuvers would not cause an unacceptable burden on the flight crew. The observers agreed that a technique was necessary to suppress the advisories created by on-ground aircraft.

The observers were not unanimous in their evaluation of the utility of traffic advisory information. Comments on the need for traffic (proximity) advisories ranged from "not needed - a distraction to the flight crew" to "traffic advisories are necessary to permit the crew to identify the threat aircraft." A general consensus of the observers was that traffic advisory information, as presented, was useful and a desirable service of TCAS.

While the Piedmont flight crews were not directly involved in this evaluation, they were aware of the project and asked many questions on system operation, operational installation, and performance. Toward the end of the evaluation period, the flight crew would often ask if a particular aircraft were causing either a traffic advisory or resolution advisory. Some crew members became well enough versed on the operation of the TCAS logic that they could generally discriminate between visually acquired aircraft that would cause an advisory and those that would not. This comprehension, without formal training, indicates that TCAS can be integrated into air carrier operations with a relatively modest training program.

CHAPTER SEVEN

CONCLUSIONS

The operational evaluation of the TCAS met the objectives set forth in Section 1.2. It provided an extended period of system operation in an airline operational environment, and it provided a data base to use in evaluating the compatibility of the TCAS with air carrier operations.

7.1 DESENSITIZATION

The desensitization technique used in the test system did not provide the desired degree of discrimination between airborne and on-ground aircraft. The technique used a fixed boundary at 500 feet above ground level to permit display of resolution advisories. Traffic advisories were displayed at any time the aircraft was airborne. A very large number of traffic advisories (48 percent) and a significant number of the resolution advisories (21 percent) were generated by on-ground aircraft.

A better technique, using the difference between own aircraft height above the ground and height above the intruder was developed and recommended to the FAA, but it has not yet been tested.

Elimination of advisories caused by on-ground aircraft will greatly reduce advisory rates and result in fewer flight crew demands. Recognizing this effect, the data analysis primarily concentrated on advisories caused by airborne aircraft.

7.2 INSTALLATION

The installation requirements of the TCAS in the two test aircraft were very similar to those expected for productio.. systems, with the exception of the installation of the display system. There were no notable installation problems and the integration of TCAS with the other aircraft systems did not degrade the performance of those systems. One missing wire initially resulted in erronous altitude sensing, and the recorder software interface caused system hangups, but such problems are not unusual for a newly installed system.

7.3 SATURATION

The TCAS did not encounter traffic densities high enough to cause it to reduce interrogation power. There were no observed cases where the TCAS processor did not have sufficient idle time to process all the replies to the TCAS interrogator.

7.4 TRAFFIC ADVISORY RATES

The frequency of traffic advisories against airborne aircraft averaged one advisory each 5.13 hours. That rate equals approximately one per day for a given flight crew, and is low enough to be acceptable in air carrier operations.

7.5 RESOLUTION ADVISORY RATES

Resolution advisories of airborne aircraft averaged one each 37.2 hours. This equals approximately two per month for a given flight crew. If it is assumed that not more than 50 percent of the resolution advisories require corrective action on the part of the crew, a particular flight crew would respond about once each month. This appears to be an acceptable rate to flight crews. Even in those cases where a TCAS corrective advisory is given, the flight crew may not be required to deviate from the planned flight path because the conflicting traffic is in sight, and separation has been coordinated with the other aircraft through an air traffic control facility.

7.6 USE OF PROXIMITY INFORMATION

The TCAS provided a graphic display of range, bearing, and relative altitude for potential threat aircraft. That information was first displayed when a target met certain minimum tau or range values, the exact value being determined by the altitude of the test aircraft. This information was available for both traffic advisory and resolution advisory classification of intruders.

Observer reaction to the proximity information varied. Some observers believed that a simple display of the TCAS-computed resolution advisory was adequate and that proximity information would require the flight crew to divert their attention from the primary time-critical task of responding to the RA to a secondary task of visually acquiring and correlating the threat aircraft.

Some observers believed that proximity information provided valuable data necessary for the flight crew to anticipate an RA and make a more timely, more moderate response to it.

The majority of the observers believed that the proximity information would assist the flight crew in understanding the cause of an RA would help identify the threat aircraft when more than one other aircraft is nearby and would aid in monitoring the effectiveness of the escape maneuver.

GLOSSARY

This glossary explains terms and expands acronyms used in this report.

AGL - Above Ground Level

ATC - Air Traffic Control

ATCRBS - Air Traffic Control Radar Beacon System

Bleed Air - Heated air drawn from one of the compressor stages of a turbine engine.

CAS - Collision Avoidance System

Contact Approach - Conduct of the final segment of a flight, including maneuvering and spacing of an aircraft in relation to other aircraft, whereby the pilot accepts the responsibility for safety separating his aircraft operating in the vicinity of the airport.

CRT - Cathode Ray Tube

DME - Distance Measuring Equipment

E&E - Electrical and electronic compartment. The space in the aircraft that contains the remotely installed avionic equipment.

ER250-2 - The FAA Engineering Requirement that defined the system to be built by Dalmo Victor, and the acceptance test for the system.

FAA - Federal Aviation Administration

IFR - Instrument Flight Rules

GFE - Government Furnished Equipment

GLOSSARY (continued)

IVSI - Instantaneous vertical speed indicator. The instrument that shows a pilot the current vertical rate of his aircraft.

MOPS - Minimum Operational Performance Specification

MSL - Mean Sea Level

Performance Level - One set of tau values, minimum vertical separation values, and minimum range values that were the basis for declaring a specific target a threat or not a threat. Performance levels were established in the logic for defined altitude bands.

RA - Resolution Advisory

Resolution Advisory - A graphic presentation of a computed escape maneuver, e.g., a lighted arrow pointing up for a CLIMB advisory. Presented on the modified IVSI.

RF - Radio Frequency

SRDS - System Research and Development Service

STC - Supplemental Type Certificate

TA - Traffic Advisory

Tau - An estimate of the time to point of closest approach derived by dividing range by range rate.

TCAS - Traffic Alert and Collision Avoidance System

TCAS II - The FAA-defined airborne collision avoidance system with capability for display of traffic advisories and resolution advisories to the flight crew, coordinating resolution maneuvers with other TCAS II equipped aircraft, transmitting maneuver intent to TCAS I equipped aircraft and ground installations, and operating in airspace densities of .3 aircraft per square nautical mile.

GLOSSARY (continued)

Traffic Advisory - A display of bearing, range and relative altitude of another aircraft. During this evaluation the traffic advisory was presented on the CRT display of the control/display unit.

VHF - Very High Frequency

VMC - Visual Meterological Conditions. Weather conditions that permit operation of the aircraft by reference to outside features.

VSL - Vertical Speed Limit

VSM - Vertical Speed Minimum

APPENDIX A

OBSERVER TRAINING

APPENDIX A

OBSERVER TRAINING

Cockpit test observers with extensive aeronautical experience collected data on the operational effectiveness of TCAS. Observers were provided from the Airline Pilot's Association (ALPA), Airline Transport Association (ATA), Federal Aviation Administration (FAA), and ARINC Research Corporation. (See section A-6 Participating Observers). The TCAS control display units and modified IVSI's were installed in the cockpit so that it could be viewed by the test observers, but was outside the view of the flight crew. The test observers recorded objective data on the flight conditions at the time of the alert and made subjective assessments on the utility of the displayed traffic and resolution advisaries. They were asked to record location, flight conditions, aircraft configuration, ATC situation, and flight crew activities at the time of the TCAS alert. The observers made subjective evaluations of the utility of the displayed resolution advisary in the context of the planned actions of the flight crew, ATC clearance, and communications among the controllers and aircraft during the alert incident.

In order to carry out their intended function, test observers had to be familiar with air carrier flight deck procedures, air traffic control procedures, TCAS concepts and operation of the Dalmo Victor avionics and recorder system.

Observer training sessions took place prior to the start of the evaluation program. This training included briefings on the TCAS concept of operation, description of the operation of the Dalmo Victor equipment, explanation of the data collection forms and voice recorder operation, and orientation on administrative procedures. The training periods included at least one flight aboard the FAA engineering test aircraft where the trainees could see the system in operation, become more familiar with the Boeing 727 aircraft and cockpit, and practice using the data forms and tape recorder.

Each observer was issued appropriate flight deck authorization by the air carrier and appropriate FAA air carrier inspection office.

It was anticipated that not every observer would be able to attend the scheduled training sessions or have extensive experience with this or similar CAS systems. Each participant was accompanied by an ARINC

representative for at least part of his first scheduled flight aboard a Piedmont Airlines 727 aircraft equipped with TCAS. Items introduced during the training sessions were again covered during these familiarization flights. These instructional flights increased observer confidence and clarified the concept of their participation in this evaluation.

Prior to their introduction to the Piedmont installation, each prospective observer was sent literature including the background of this concept of collision avoidance, the Mitre collision avoidance logic implemented in the Dalmo Victor system, and a copy of the Experimental Test Plan for the Operational Evaluation of the Active Beacon Collision Avoidance System. Besides information covering virtually every aspect of test program, the experimental test plan contained specific instructions pertinent to the test observers. Items addressed included preflight protocol for riding jumpseat on Piedmont Airlines, crew briefing, TCAS operation, contents of on-board observer kit, observer role, inflight procedures, post flight administrative tasks, instructions in the event of system malfunctions, instructions for observer Checklist/Records, TCAS self-test/malfunctions, CRT Display Traffic Advisory symbology and TCAS modified IVSI Resolution Advisory command indications. These items are excerpted in sections A-1 through A-5.

OBSERVER INSTRUCTIONS

A-1. FLIGHT OBSERVER

The flight observer performs the most important role in the evaluation of the Active BCAS. He is the man on the spot who uses his aeronautical training and experience to evaluate the potential impact of the Active BCAS on the operation of the aircraft and on the ATC system. The flight observer is expected to mentally project himself into the role of pilot flying the aircraft.

The flight observer must not in any way interfere with the flight crew and the performance of their duties. The flight observer is a guest on the flight deck and must not interject his opinions or comments into the flight crew's actions, regardless of the observers aeronautical ratings, experience, or position.

A-2 ADMINISTRATIVE TASKS

A-2.A Scheduling

ARINC will make advanced arrangement for space aboard the test aircraft.

A-2.B Preflight

The observer should arrive at Piedmont operations at least 45 minutes before scheduled departure time. Upon presentation of his flight authorization, the observer should ask to go aboard the aircraft where he should again present his authorization to the captain, and briefly state his reason for being aboard.

The observer should explain to the captain that he will be making periodic voice recordings describing the flight path, location, traffic situations and crew workload. The observer should tell the captain that he will be following and copying the ATC clearances issued to the flight. The observer should carefully point out that these records and recordings are being made only for collection of BCAS performance data and will not be used for any other purpose. It may be explained that unsolicited crew comments following an incident may be helpful.

BCAS manual self test should be performed before flights (See A-5 BCAS Self Test/Malfunctions).

A-2.C Observer Kit

On obard the test aircraft will be an observer kit with earphones, cassette recorder and cassettes, mailing envelopes, observer record/ checklists, etc.

A-2.D Inflight

The observer is to project himself into the pilot's role as if he were flying the aircraft. During the flight the observer must maintain an informal record of the clearances issued by ATC, along with the times they are issued. He should maintain a record of flight progress with a notation of the time the flight crosses VORs, departs and altitude, arrives at an assigned altitude, enters holding, departs holding, and any other significant events that occur during the flight.

If a BCAS alert is given or if an alert should have been given, the observer should complete a checklist and narrative audio record of the incident as outlined. (See A-3 Observer Checklist/Record.)

A-2.E Post Flight

A completed checklist and tape cassette should be mailed to ARINC Research in the envelope provided at the end of each days flight aboard a specific test aircraft. If the observer rides on two different test aircraft in one day, he should mail two separate envelopes, one for each aircraft.

Should any difficulty be encountered, inform ARINC (301)266-4733/ 4729.

A-2.F Malfunction

In the event of any indication of a failure or degradation of BCAS performance, perform and repeat as necessary a manual self test (See A-5 BCAS Self Test/Malfunctions). Note the failure mode, indications, and time of test. Pass to the crew any information pertinent to log entry of a BCAS failure. Inform ARINC of any difficulty or BCAS failure as soon as practicable (301)266-4733/4729. ARINC will be responsible for repair of BCAS.

A-3. OBSERVER CHECKLIST/RECORD

A-3.A Instructions for Checklist

Phase of flight - check one box

1. Departure - takeoff until established in a flaps-up climb at stabalized speed and power.

2. Climb - from first stabilized flaps-up climb through level-off and speed stabilization at first assigned cruise altitude. Climb includes any holds or intermediate altitude assignments made for the convenience of ATC

3. Cruise - from speed and power stabilized level flight until start of descent into terminal area.

4. Descent - from end of cruise until entry into the approach profile as depicted on the approach chart. Includes profile descents, STARS and unpublished arrival routing, but excluding holding.

5. Approach - from the start of the published approach procedure until touchdown for visual approaches, from point where ATC clears the aircraft for a visual approach.

6. Holding - any holding regardless of where it occurs - climb - cruise - descent or approach.

How Flying - describes the manner the flying officer is using to control the aircraft. Select as many as applicable.

1. Hand - hand flying with no autopilot assistance - autopilot disengaged in all modes.

2. Autopilot - autopilot is engaged in at least one channel.

3. VOR/LOC - autopilot engaged in VOR/LOC - either amber or green light on.

4. APP - autopilot engaged in approach mode (AUTO G/S or MAN G/S - either amber or green light on.

5. Altitude - altitude hold engaged.

Flight Conditions - select applicable boxes

1. IMC - in clouds majority of time
2. VMC - outside clouds
3. Marginal - officially VFR, but flight conditions (sun, haze, smog) are marginal IFR.
4. Contact Approach - crew has accepted clearance for a contact approach. (This box may be checked in addition to IMC or VMC).

Systems - describes the condition of various systems at the time the alert occurs. Check as many as applicable.

1. Flaps - flaps are extended to some extent. If possible, enter the degree, e.g., 2°, 15°.
2. Gear - landing gear selector "down" and gear in transit or down.
3. Speed Brakes - speed brakes deployed
4. Power - power reduced below cruise power setting

Flight Path - describe the flight path at the time of the BCAS alert. Select as many as appropriate. All terms are self-explanatory.

1. Climbing
2. Descending
3. Level
4. Straight Ahead
5. Turning Left
6. Turning Right

Airspace Density- an evaluation of the relative level of traffic density about your aircraft. This information is derived from watching outside and listening to the radio.

1. Heavy - more aircraft than you would expect at the location where the alert occurs.
2. Average - about the number of aircarft you would expect at the location where the alert occurs.
3. Light - less aircraft than you would expect at the location where the alert occurs.

OBSERVER CHECKLIST/RECORD

OBSERVER NAME: ______________________________ DATE: ____________________

Phase of Flight
- Departure ________
- Climb ________
- Cruise ________
- Descent ________
- Approach ________
- Holding ________

How Flying
- Manual ________
- Auto Pilot ________
- Approach ________
- Altitude ________

Flight Conditions
- IMC ________
- VMC ________
- Marginal ________
- Contact App ________

Systems
- Flaps ________
- Gear ________
- Speed Brakes ________
- Power ________

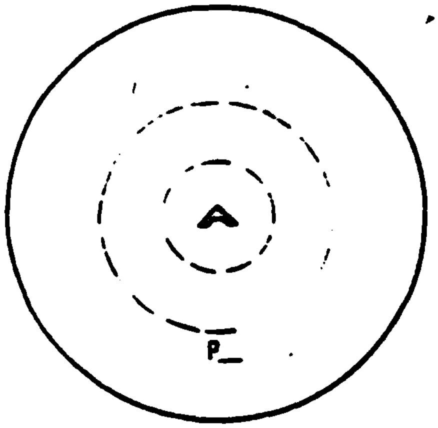
Airspace Density
- Heavy ________
- Average ________
- Light ________

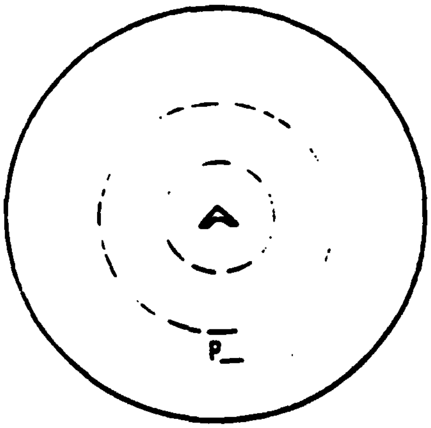
Flight Path
- Climbing ________
- Descending ________
- Level ________
- Straight ________
- Left Turn ________
- Right Turn ________

Workload
- Busy ________
- Average ________
- Light ________

TAPE RECORDER ITEMS

Time/Location
Own Aircraft Intentions
ATC Advisory
Own-Intruder Relationship
(Azimuth, Range, Elevation, Climb/Descent)
Sighting
Timeliness
Correctness
Usefulness
Disruption
Resolution
Undetected Intruder
Value of PWI
Comments





Workload - an evaluation of the relative busyness of the flight crew at the time the alert occurs.

1. Busy - The flight crew is almost continually involved in the conduct of the flight. Some low-priority tasks may be delayed.
2. Average - The crew is involved in conduct of the flight, however it has some spare time. There are no delayed tasks, however the crew may be occupied with optional or anticipatory tasks.
3. Light - the crew is involved in routine duties only. There are no delayed tasks to be performed and no optional or anticipated tasks are in progress.

A-3.B <u>Observer Tape Recorder Record</u>

The observer will record a summary of each alert incident as soon as possible after the alert incident, using the portable tape recorder in the observer kit. The narrative summary supplements and amplifies the data recorded on the observer record and permits the observer to make a subjective evaluation of the alert, its probable impact on crew duties if it had been given to the crew, and its timeliness and appropriateness.

The narrative should include subjective comments on the 10 areas listed below and outlined on the alarm record sheet.

1. Time/Location. Given the time the alert tone was first heard, and the geographic location of the alert, e.g., "at 1728 Greenwich, at the 19.2 mile DME on the 093° radial of Franklin VOR at 5000 feet".
2. Own Aircraft Intentions. State the flight's planned actions, e.g., "We were descending from 9000 to 2000 and transitioning to Coley intersection for an ILS approach to Runway 5 at Norfolk".
3. ATC Advisory. State whether ATC had issued an advisory, and the ATC facility which was controlling the flight., e.g., "Norfolk approach control advised us of traffic inboard from Cofield at 2000 feet".
4. Own-Intruder Relationship. Give any ATC instructions that limit your flight in relation to the intruder, e.g., "Cleared to follow a United 737 now 12 miles outside the marker".
5. Sighting. Did the crew or the observer have the intruder or another aircraft in sight prior to the alert?, e.g., "The first officer acknowledged he had the United in sight at 10 o'clock".
6. Timeliness. Was the alert presented in time., e.g., "The limit descent to 500 FPM alert was given when the aircraft were still 4 miles apart. This appeared to be a little earlier than necessary".
7. Correctness. Was the alert the correct sense - would it have caused any trouble to follow? e.g., "We were descending at 750 FPM and a reduction in descent would have caused no problem".
8. Usefulness. Was the alert needed? Would it have served a useful purpose? e.g., "We would have been 3 miles behind the United when we intercepted the ILS. The alert was not needed, however it reinforced the ATC traffic call".

9. Disruption. Would the alert have caused a disruption in the flight crew routine? e.g., "Compliance with the alert would not have caused any deviation from normal flight path at this point in the approach.
10. Resolution. How was the situation that caused the BCAS laert resolved by ATC and the flight crew? e.g., "ATC asked us to slow to 150 which gave us additional spacing on the United".
11. Undetected Intruder. Note any aircraft that should have been detected by BCAS or would have been detected if it had an operating MODE C transponder (e.g., "Captain sighted a small Cessna off left wing. Potential intruder, no indication, probably MODE A only.")
12. Value of PWI's. Any comment on usefulness of traffic advisory CRT information (e.g., "Proximity information would have caused me to consider a speed reduction before it was given by ATC, and probably before the alert sounded.")
13. Comments. Give any comments you wish about the alert incident.

A-4. BCAS SELF TEST/MALFUNCTIONS

BCAS will periodically perform an automatic self test. The observer should perform a manual self test before each flight and in the event of any indication of a failure or degradation of BCAS performance.

NORMAL OPERATION

1. Self test switch - Down (automatic test)
2. The display will appear as in Figure A-1.

   An own aircraft symbol and range ring indicates normal operation

   A blinking "F" indicates a failure

   No display indicates a failure (CHECK BRIGHTNESS)
3. If "F" or abnormal display appears, perform a manual self test to to isolate failure.

MANUAL SELF TEST

1. Self test switch - Up (manual test)
2. The display will appear as in Figure A-2.

   A "P" will indicate system is operational (manual test complete)

   No display indicates a failure (CHECK BRIGHTNESS)

   X only CPU failed

RF and Processor Failure Indications

F1 Transmitter
F2 DF antenna and receivers
F3 RAM/ROM
F4 ATCRBS decode
F5 DABS decode

Display Failure Indications

D1 ARINC timeout (no messages)
D2 RADV timeout (no resolution advisory message)
D3 Display not done (to many symbols to display)
D4 ARINC parity error
D5 Que overflow (too many messages to process)
D6 Bad data set number (bad data)
D7 Invalid RA command (bad data)

3. Note failure mode, indications, and time of test.
4. Repeat as necessary.
5. If self test failed, ask crew to secure BCAS by pulling the four BCAS circuit breakers.
6. Pass to crew any information pertinent to log entry of BCAS failure.
7. Inform ARINC of any BCAS failure as soon as practicable (301)266-4733/4729. ARINC will be responsible for repair of BCAS.

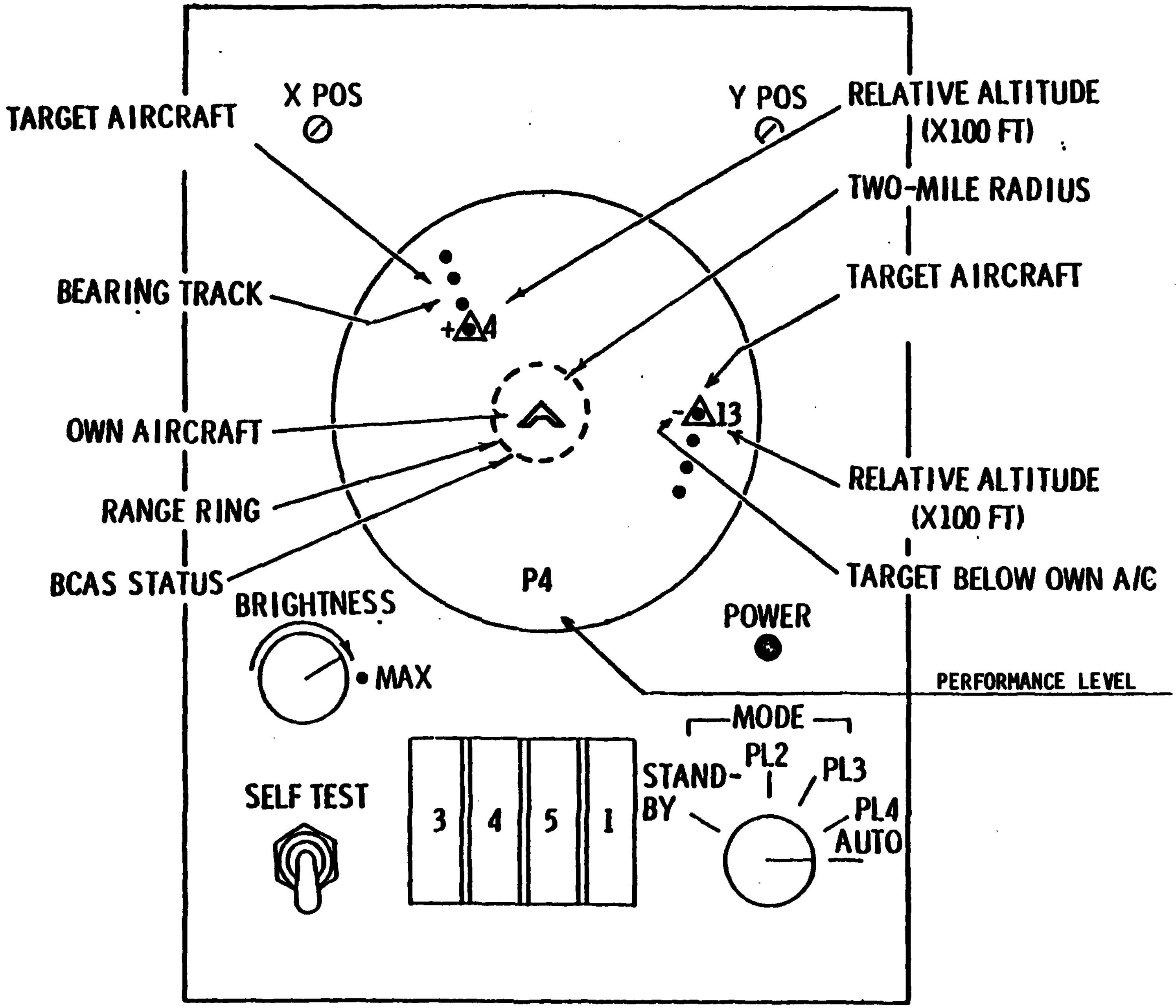


Figure A-1. BCAS CRT DISPLAY

FAIL SYMBOLS
1) BLANK DISPLAY
DISPLAY FAILED
2) X ONLY
CPU FAILED
3) F1, F2, ETC
ONE OF THE RF
OR PROCESSOR
TESTS FAILED

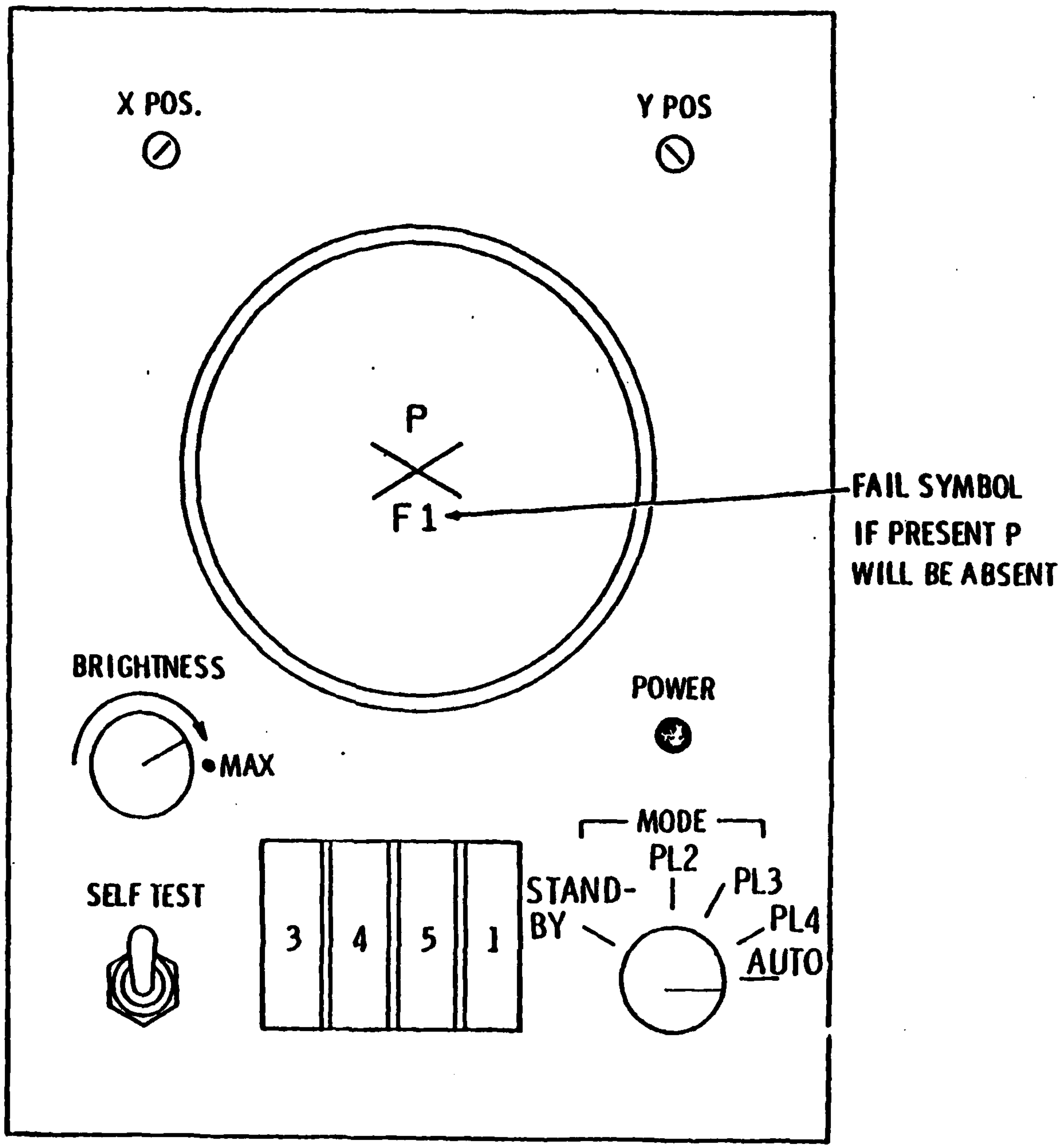
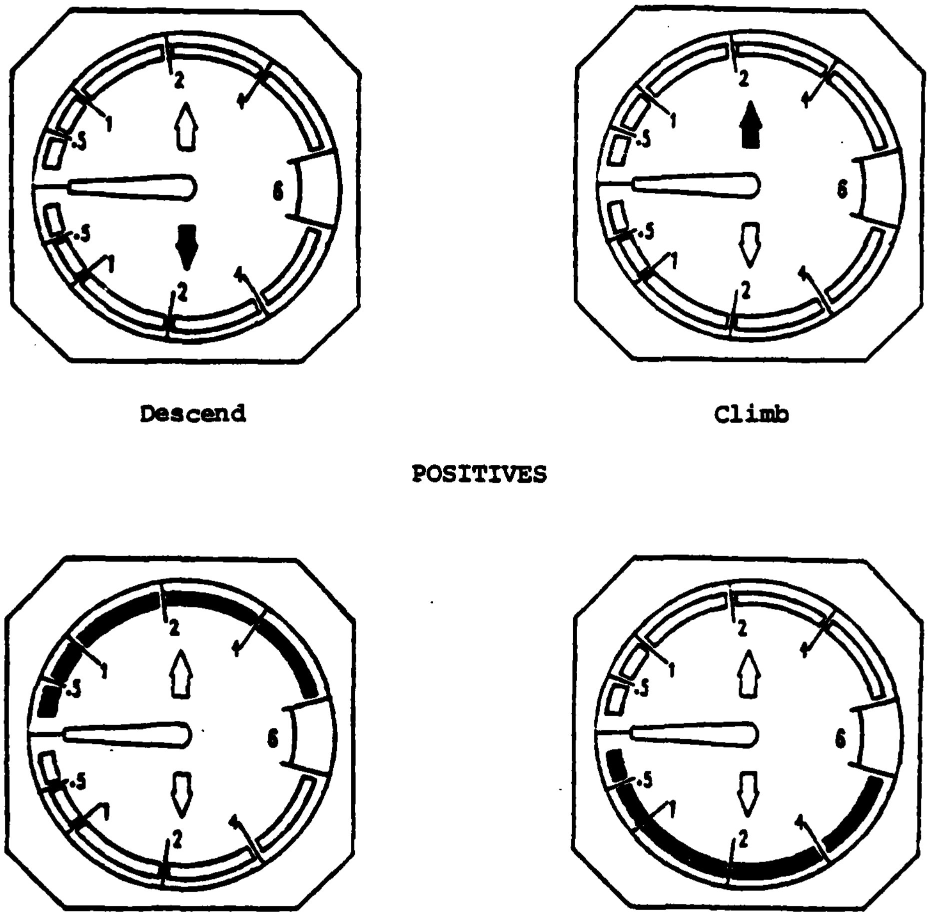


Figure A-2. BCAS SELF TEST FAILURE INDICATIONS

A-5. BCAS IVSI



Descend   Climb

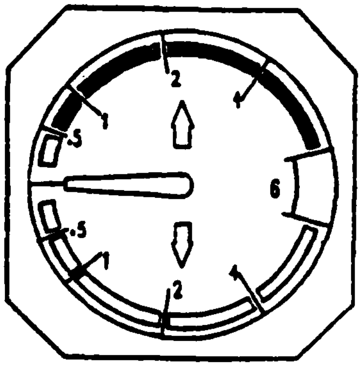
POSITIVES

Don't Climb   Don't Descend

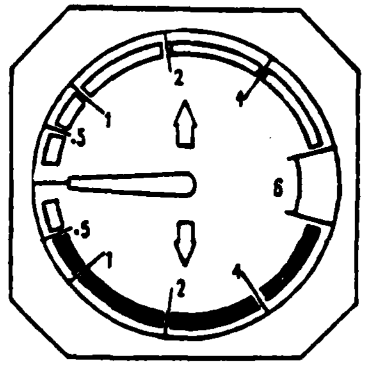
NEGATIVES

BCAS resolution advisories are displayed by lighted descend or climb arrows or lighted segments on the face of the IVSI modified for BCAS. These indications are shown by shaded portions in Figures A-5.A, B, C. For this evaluation, other functions on the BCAS IVSI are inoperative.

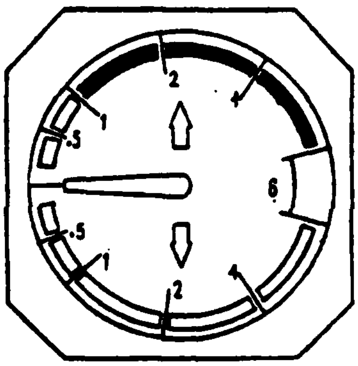
Figure A-5.A. POSITIVE/NEGATIVE BCAS IVSI RESOLUTION ADVISORY INDICATIONS



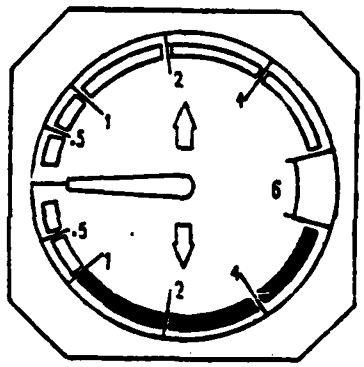
Don't Climb Faster than 500 fpm



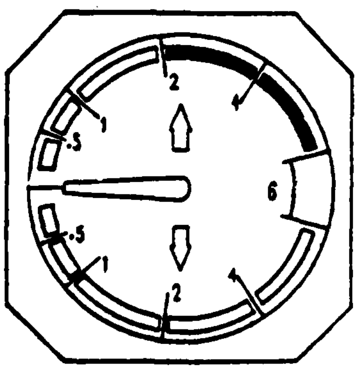
Don't Descend Faster than 500 fpm



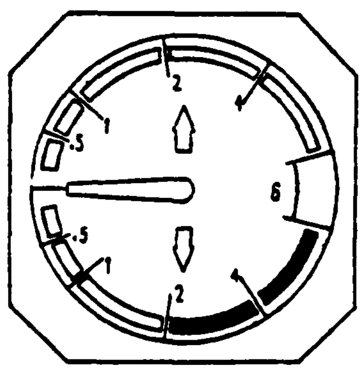
Don't Climb Faster than 1,000 fpm



Don't Descend Faster than 1,000 fpm

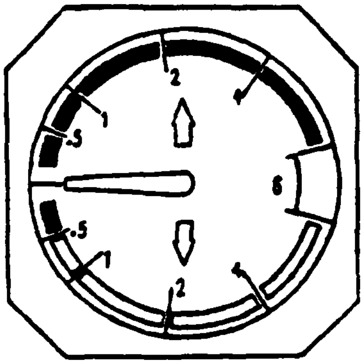


Don't Climb Faster than 2,000 fpm

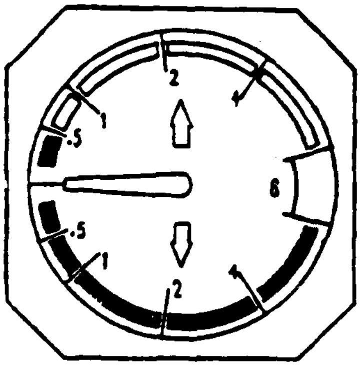


Don't Descend Faster than 2,000 fpm

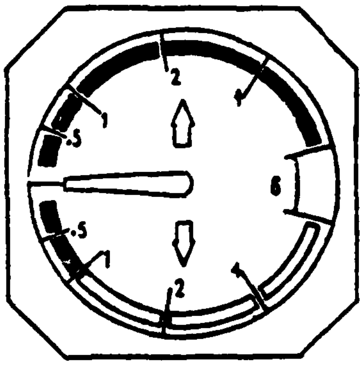
Figure A-5.B. BCAS VERTICAL SPEED LIMIT INDICATIONS



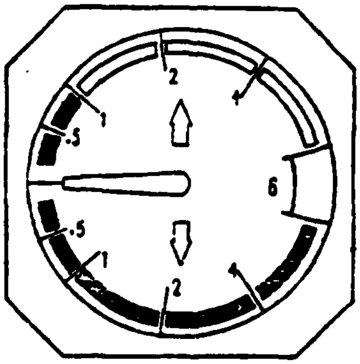
Descend Faster than 500 fpm



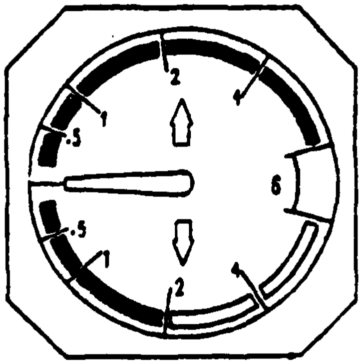
Climb Faster than 500 fpm



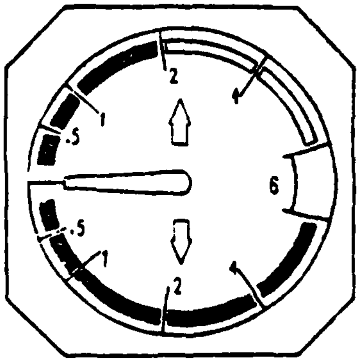
Descend Faster than 1,000 fpm



Climb Faster than 1,000 fpm



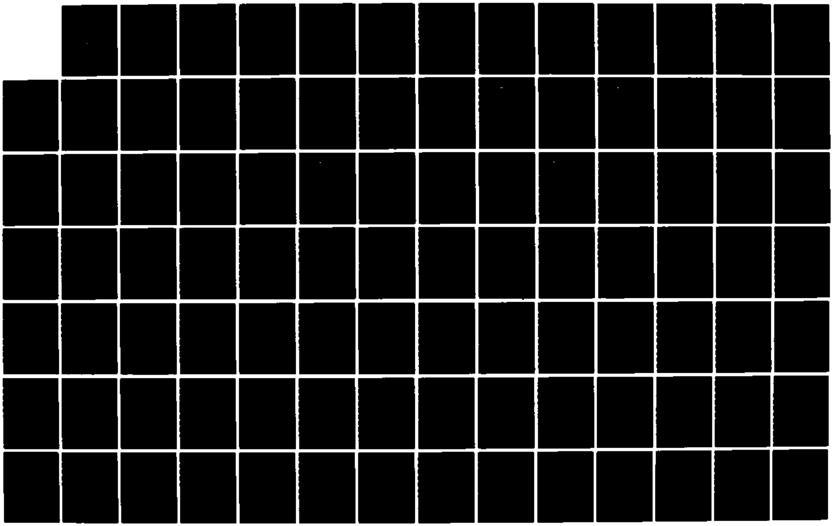
Descend Faster than 2,000 fpm

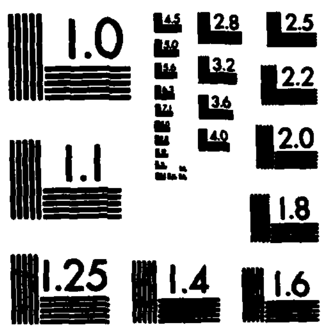


Climb Faster than 2,000 fpm

Figure A-5.C. BCAS IVSI VERTICAL SPEED MINIMUM INDICATIONS

AD-A146 435 IN-SERVICE EVALUATION OF THE DALMO VICTOR ACTIVE BEACON 2/3
COLLISION AVOIDAN..(U) ARINC RESEARCH CORP ANNAPOLIS MD
T P BERRY ET AL. OCT 82 1391-01-1-2810 DOT/FAA/RD-82/90
UNCLASSIFIED DTFA01-80-C-10093 F/G 17/7 NL





MICROCOPY RESOLUTION TEST CHART

APPENDIX B

RESOLUTION ADVISORY CASES

This appendix presents summaries and data on the 32 encounters that resulted in resolution advisories during the 928 hours of TCAS operational evaluation.

With the exception of four cases where the automatic recording system failed to record the data because of improper tape cassette loading, each case is accompanied by six data plots, prepared from the data recorded during the conflict. One of these plots represents the relative bearing and range of the intruder aircraft during the incident. This data is presented in a plan view format. When examining this plot, it should be recognized that a turn by either aircraft would cause a change in the relative bearing. Each symbol on this chart represents a one second update of the data, the same update rate used on all charts.

The remainder of the plots are x-y plots, with elapsed time from the start of the encounter plotted on the x-axis. X-axis values are shown on the lower of the charts on each page.

The remaining plots provide a record of the following sets of data:

a. Tau values. Both the horizontal tau (TAUR) and vertical tau (TAUV) are plotted on the same chart. The y-axis scale is in seconds. A dashed line across the chart shows the TAUR value for generation of a resolution advisory for this case.

b. Altitude separation. Two types of separation data are plotted; currently altitude separation (A) and altitude separation projected at point of closeout approach (VMD). The threat detection threshold is shown by a dashed line. Altitude separation is always given as a positive value and therfore gives no indication if the intruder was above or below the test aircraft.

c. Range information. Two types of range information are shown; Range (R) and range rate (RDOT). The range is plotted in nautical miles with the scale on the left of the plot. Range is always shown as a positive number. Range rate is plotted in feet per second with the scale on the right. Range rate may be either a positive or negative value.

d. Vertical rates. This chart shows the vertical rates of the test aircraft (ZDOWN) and the intruder (ZDINT) in feet per second. The values may be either positive or negative.

e. Range and altitude separation. Three data elements are plotted on this chart. The range (R) between the test aircraft is in nautical miles and plotted against the right scale. The test aircraft altitude (ZOWN) and the intruder altitude (ZINT) and plotted against the left scale. The three curves plotted on this chart, together with the bearing plot, provide a very good representation of the physical encounter.

At the top of the plot is a representation of the resolution advisories generated during the encounter. An arrow indicates a "CLIMB" or "DESCEND" advisory; an arrow with an X on the shaft indicates a "DON'T CLIMB" or "DON'T DESCEND" advisory; an arrow with bars on the shaft represent a "LIMIT CLIMB" or "LIMIT DESCENT" advisory, with one bar signifying 500 FPM, tow bars 1000 FPM, and 3 bars 2000 FPM. Minimum vertical speeds (VSL) are shown by an arrow with one bar near the arrowhead and one to three bars at the tail. The arrowtail bars signify minimum vertical speeds of 500 FPM (1 Bar), 1000 FPM (2 Bars), and 2000 FPM (3 Bars).

A vertical line is drawn on the plots to reference the start of an advisory.

CASE 1

Transitioning Resolution Advisory on Approach to Washington's National Airport, November 24, 1981

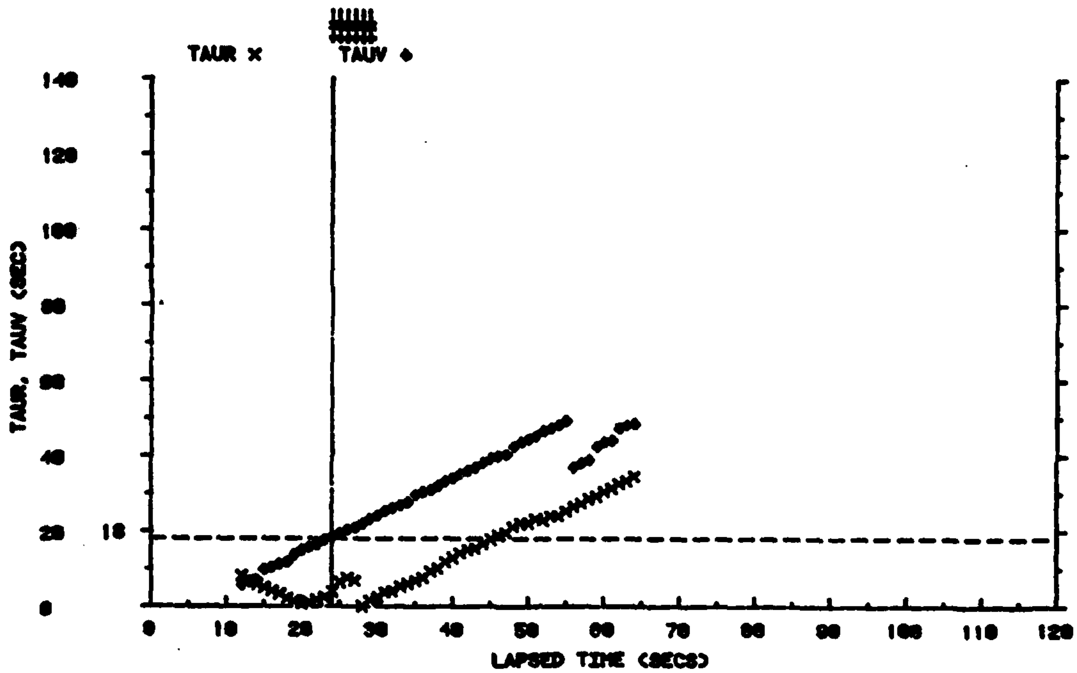
A TCAS observer from ARINC was aboard Piedmont Flight 50 from Greensboro, North Carolina to Washington's National Airport. At approximately 8:30 a.m. EST Flight 50 was descending out of 4,000 feet on approach down the Potomac River to Runway 18 when the controller advised of a small Cessna aircraft flying to the south, low over the Potomac. The aircrew and the observer had the aircraft in sight well north of the 14th Street Bridge. Flight 50 would pass to right of traffic and turn to runway heading. A DO NOT DESCEND faster than 1,000 feet per minute Resolution Advisory transitioning to DO NOT DESCEND faster than 500 feet per minute was indicated on a target displayed at the 10 to 9 o'clock position, just outside two miles range. This Resolution Advisory cleared shortly before reaching 200 feet below own aircraft. The target left the display at 9 o'clock, less than two miles when the Piedmont aircraft descended through 500 feet above ground level (AGL). At 500 feet AGL TCAS in this installation automatically changes performance level from PL 4 to PL 2. In PL 2 Resolution Advisories are inhibited. Normal operation of own aircraft in this situation closely matched the resolution maneuver chosen by TCAS.

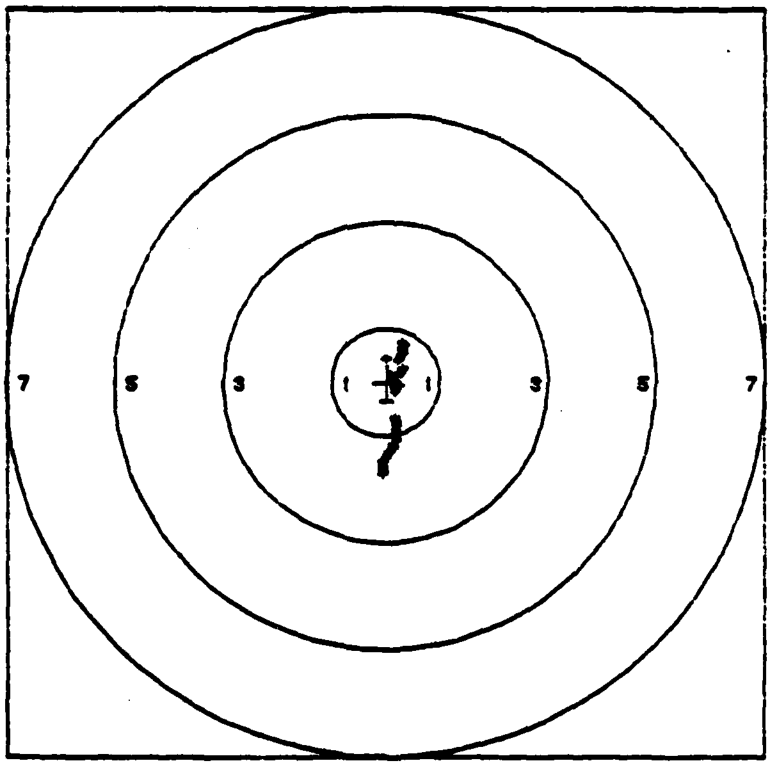
CASE 2

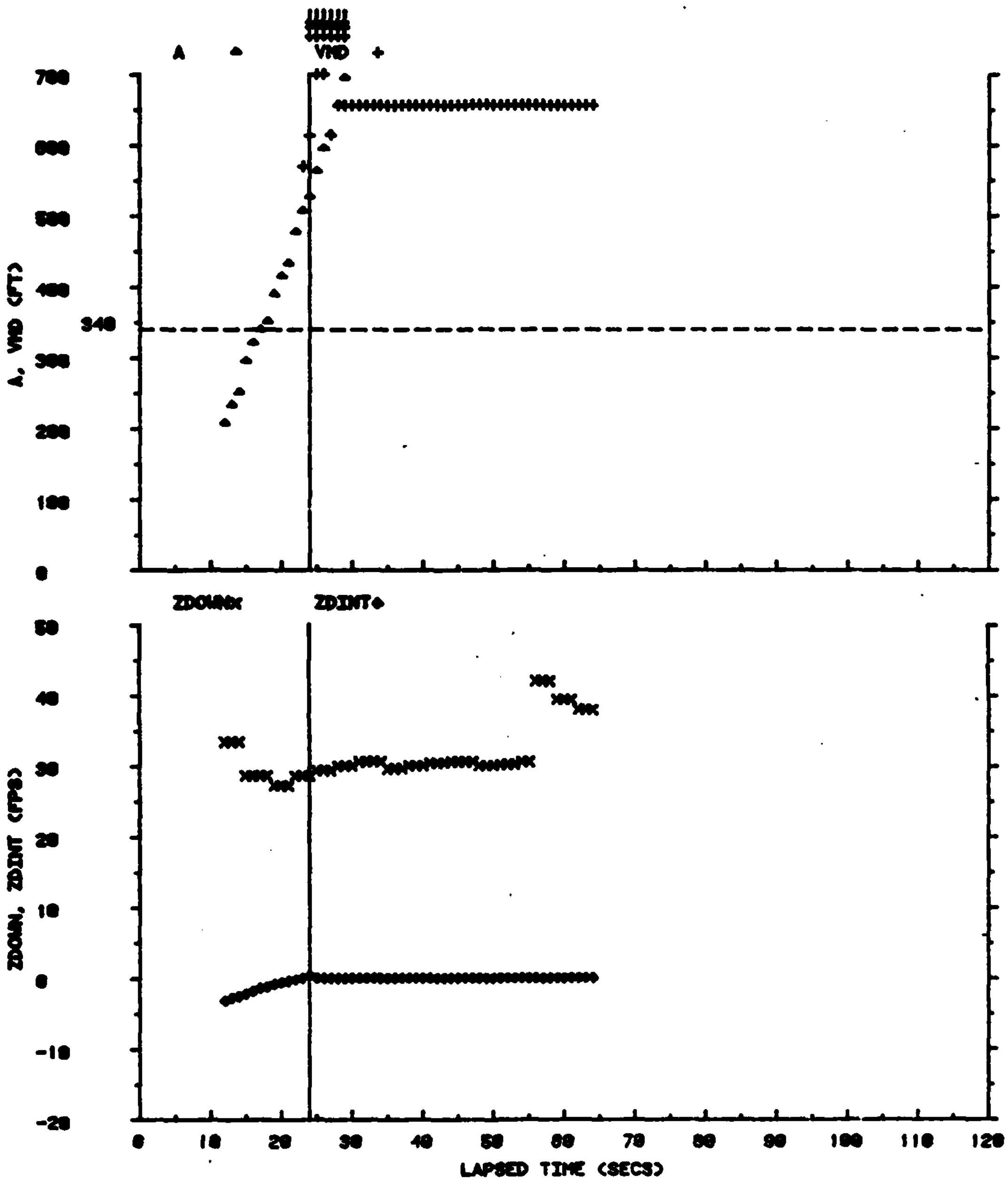
(Tape 004, Intruder 204) Don't Descend on Ground Target at Newark, November 30, 1981

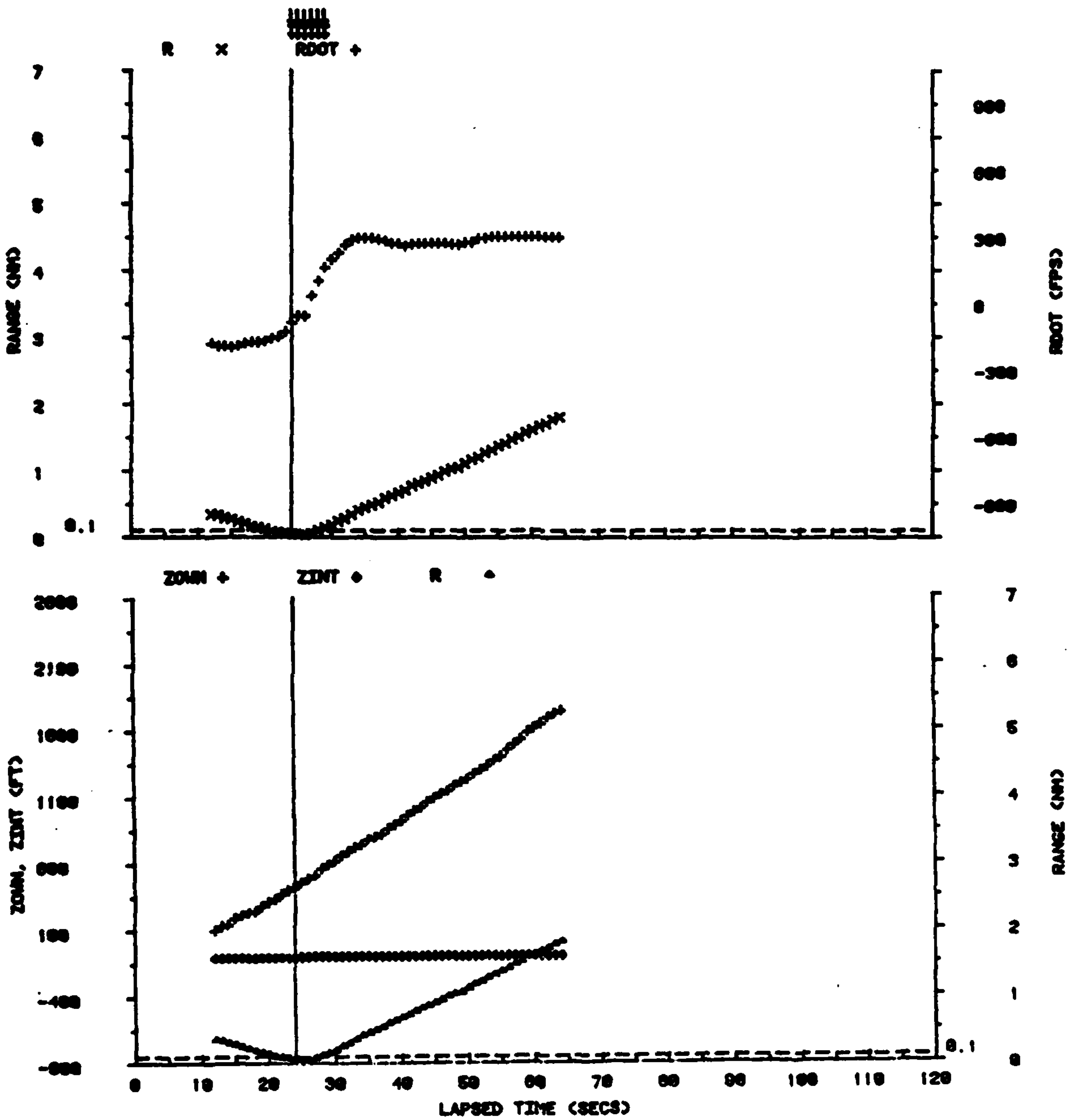
On the afternoon of November 30, 1981, an ARINC observer was aboard Piedmont Flight 55 from Newark, New Jersey to Norfolk, Virginia. Immediately upon takeoff in visual meteorological conditions the observer was alerted by the TCAS aural to traffic advisory information on the TCAS CRT. The initial target display was merged with own aircraft symbol but then trailed to the 6 o'clock position. Tower had not been in radio contact with any airborne aircraft nor were any seen. As the takeoff climb continued, the target's indicated relative altitude closely matched own aircraft altitude and the observer assumed the target to be on the ground. Immediately upon passing 500 feet above ground level (AGL), a resolution advisory of DO NOT DESCEND was indicated on the TCAS modified IVSI.

The observer concluded that this was an unnecessary alert that could have created confusion in the cockpit during a normally busy phase of flight.


TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
140
120
100
80
60
40
20
0
18
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)


7
5
3
1
1
3
5
7

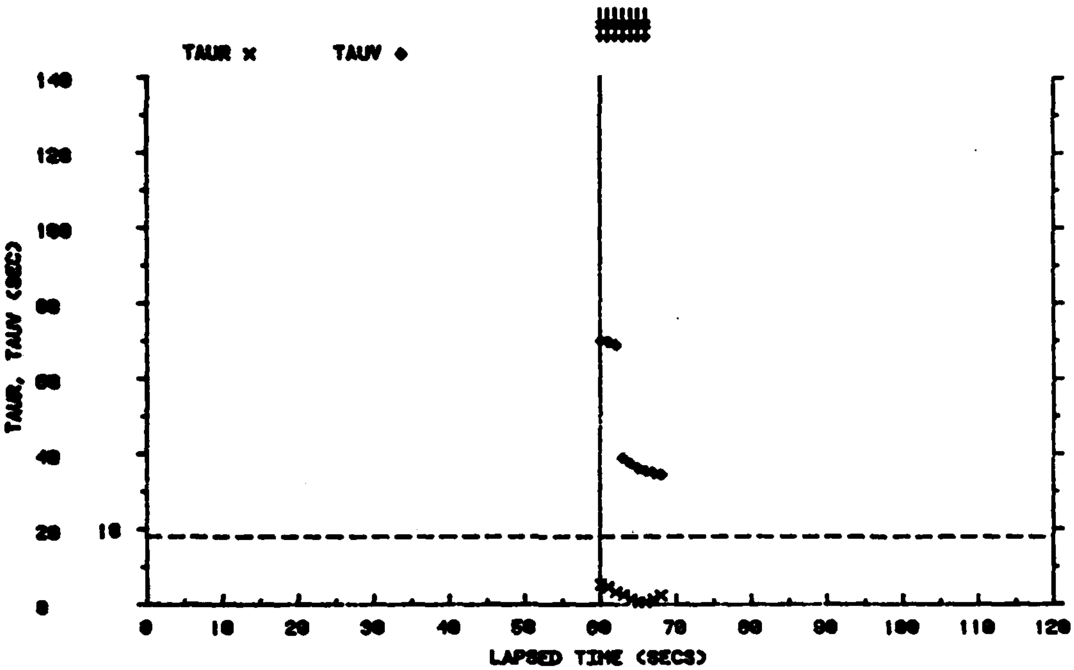

A
VND
700
600
500
400
340
300
200
100
0
A, VND (FT)
ZDOWN
ZDINT
50
40
30
20
10
0
-10
-20
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)


R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.1
ZOWN +
ZINT ◆
R *
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

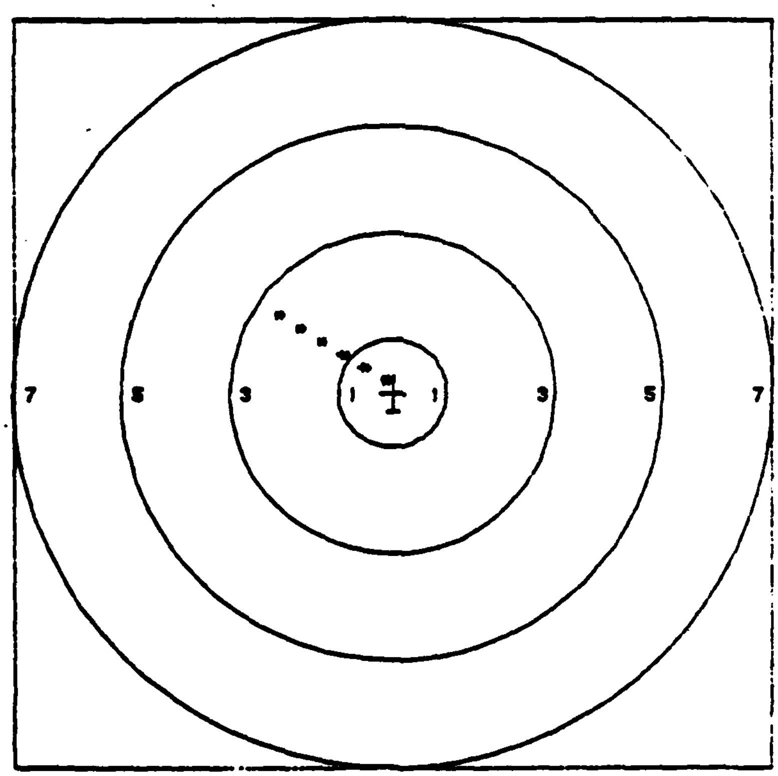
CASE 3

(Tape A009, Intruder 129) Ground Level Intruder at Chicago's O'Hare International Airport, December 3, 1981

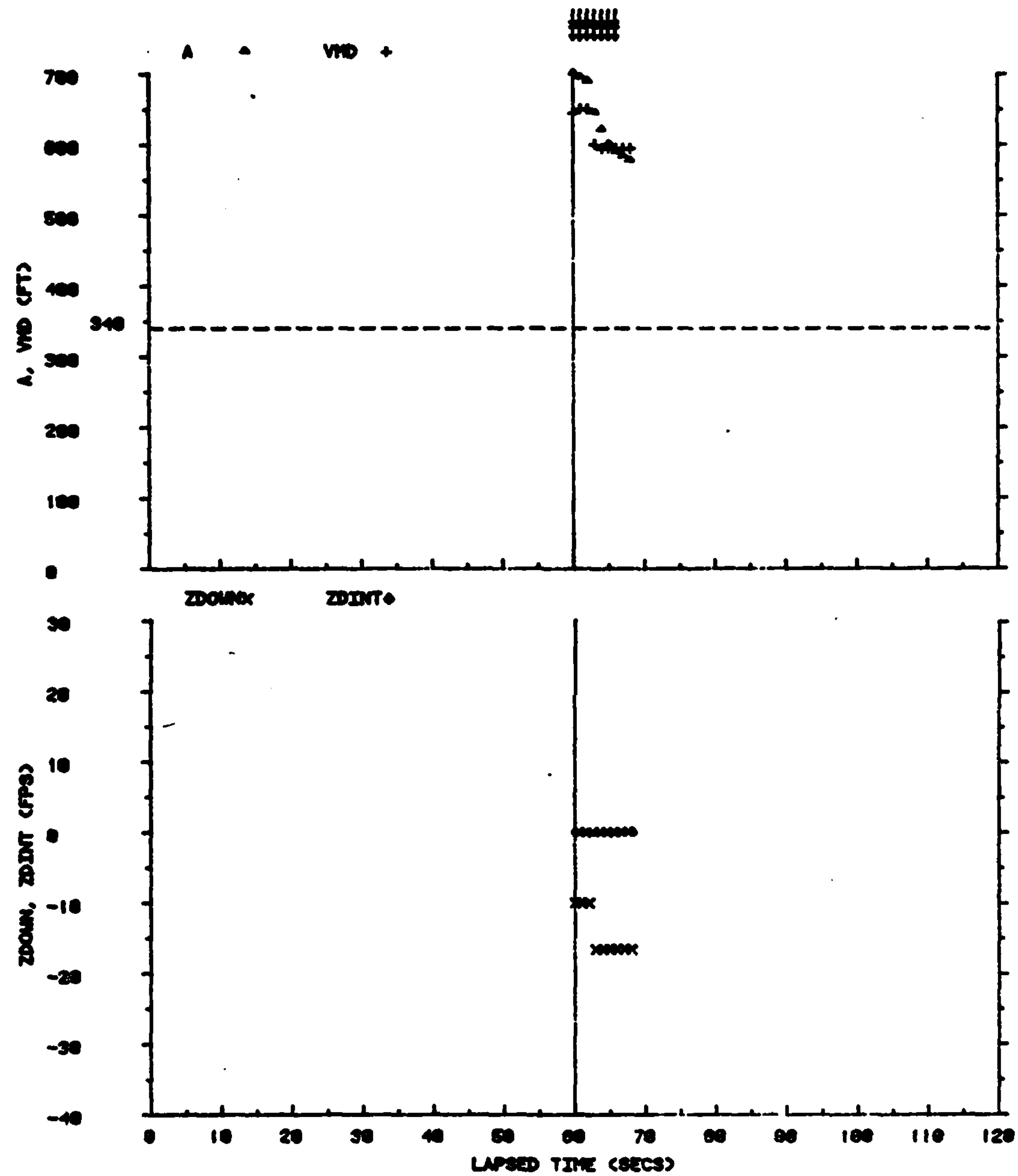
On December 3, 1981, an ARINC observer was aboard Piedmont Flight 64 from Charlotte, North Carolina to Chicago's O'Hare International Airport. At about 3:03 local time Fligth 64 was still above 500 feet above ground level (AGL) when a resolution advisory of DO NOT DESCEND was indicated on the TCAS IVSI. Traffic information indicated an intruder at ground level. Any of a number of aircraft on the ground could have caused the alert. The resolution advisory was both unnecessary and a nuisance. If followed it would have been disruptive and may have caused a missed approach.



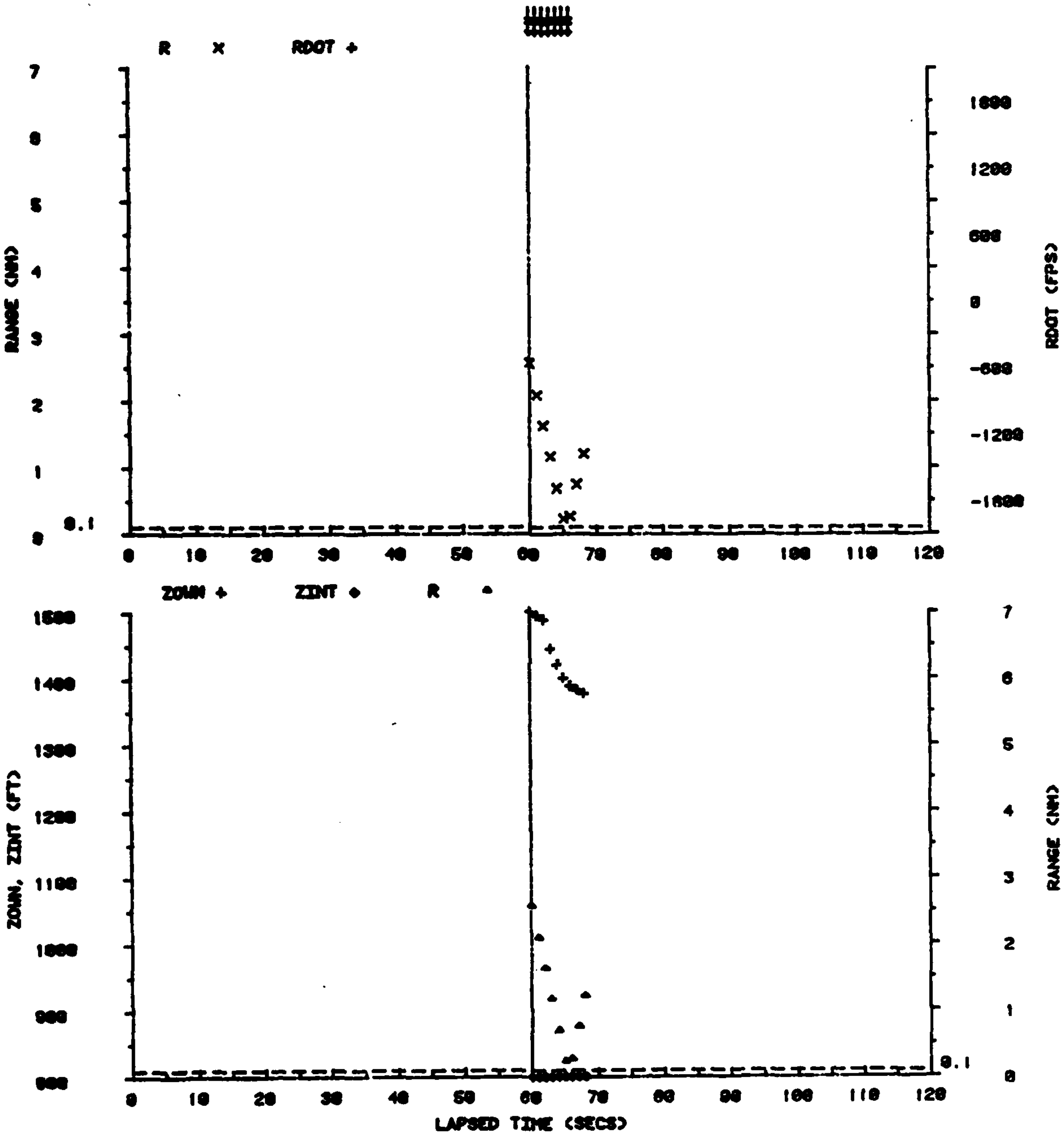
TAUR x
TAUV ◆
TAUR, TAUV (SEC)
140
120
100
80
60
40
20
0
18
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
1
1
3
5
7



A
VMD +
700
600
500
400
340
300
200
100
0
A, VMD (FT)
ZDOWN×
ZDINT◆
30
20
10
0
-10
-20
-30
-40
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



R × RDOT +
RANGE (NM)
RDOT (FPS)
0.1
ZDWN + ZINT ◆ R ▲
ZDWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

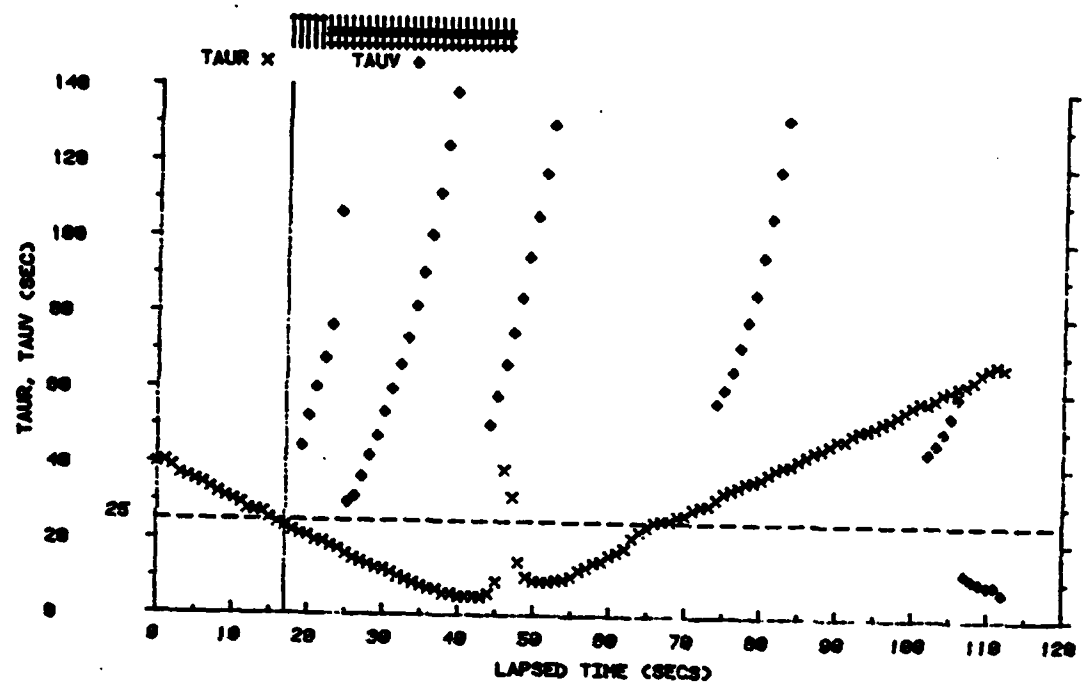
CASE 4

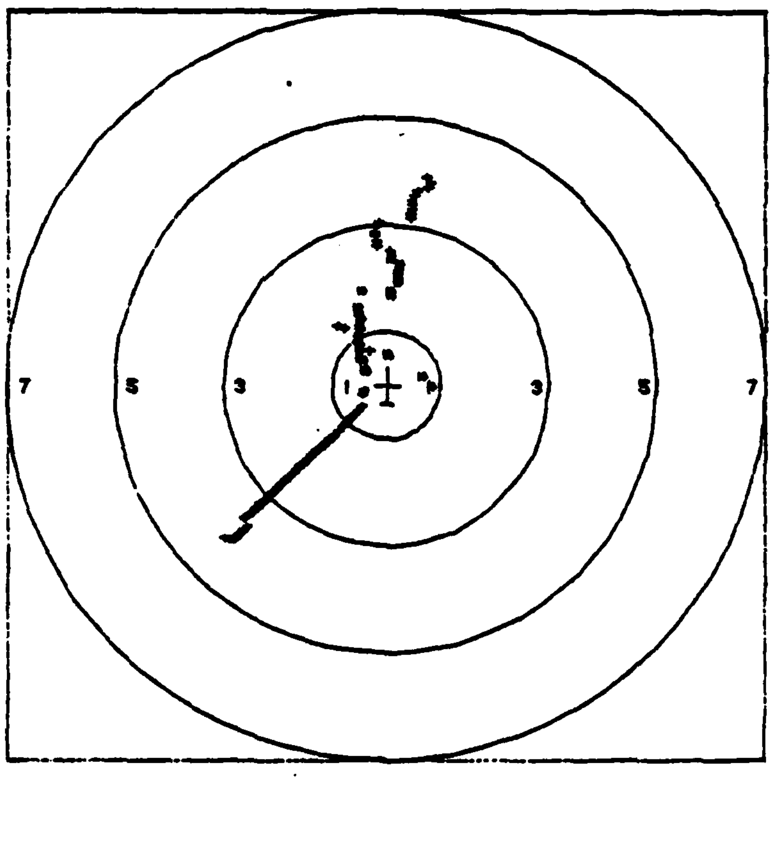
(Tape A009, Intruder 39) Transition Climb/Don't Descend on Approach to Tampa, Florida, December 31, 1981

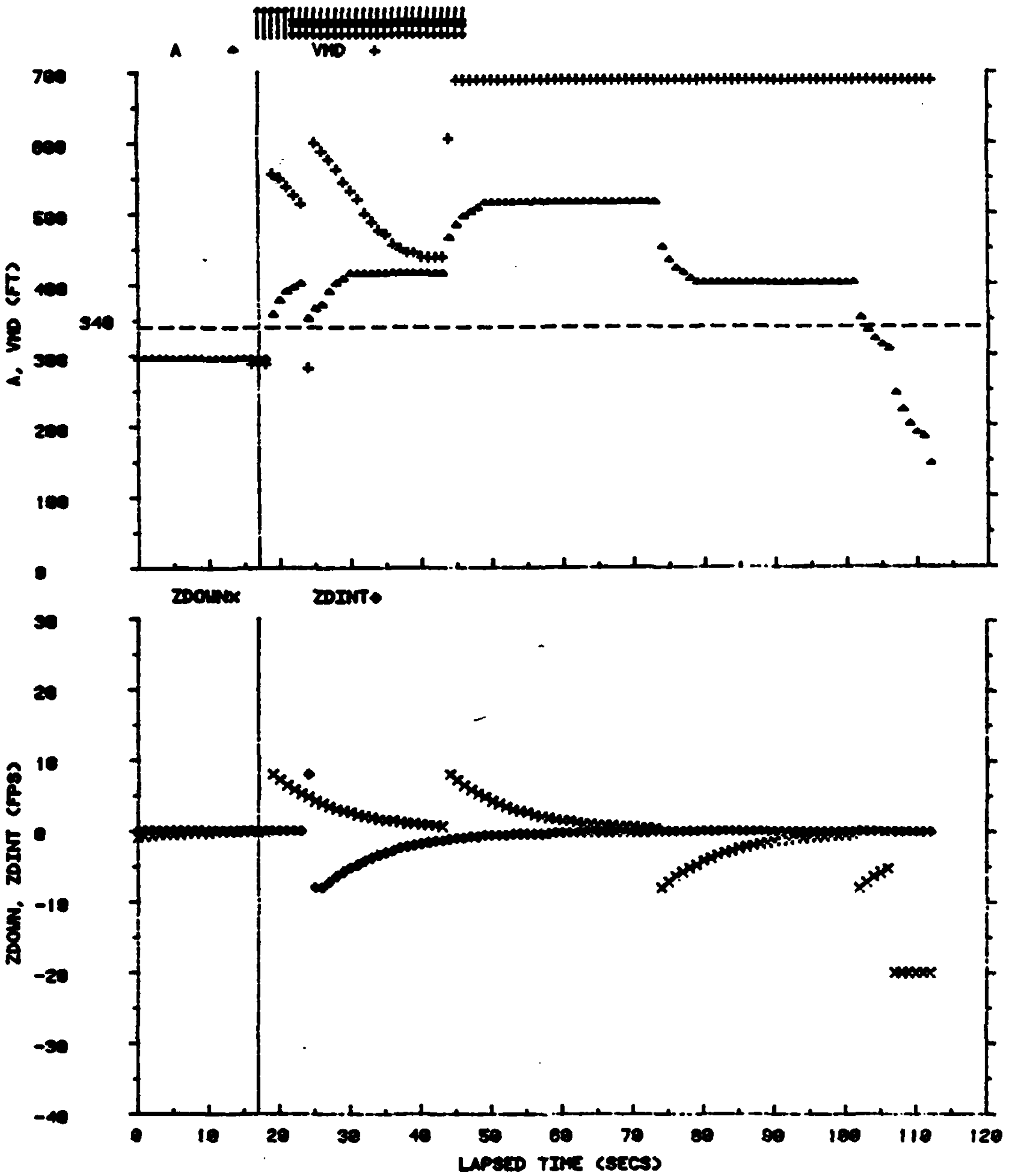
On the evening of December 3, 1981 an air carrier pilot was aboard Piedmont Flight 66 to observe the operation of the TCAS and evaluate the potential impact on crew duties of the system. At approximately 6:30 p.m. Flight 66, from Charlotte, N.C. to Tampa Florida had been cleared to descend to 4000 feet. At this time Flight 66 was approximately 18 miles east of Tampa airport and was turning to a southerly heading. As Flight 66 passed through 4100 feet, descending at approximately 600 feet per minute (FPM) a traffic advisory was given to the observer by sounding the aural alert and displaying conflicting traffic on the CRT display at 12 o'clock and 4 miles range. No traffic advisory was issued by Air Traffic Control. The intruder continued to track closer to own aircraft, still showing at 12 o'clock bearing and with range steadily decreasing. When the intruder reached the 3 mile range, the TCAS aural alert sounded again and a "DON'T DESCEND" resolution advisory was displayed on the system IVSI. At this time the intruder relative altitude showed him 300 feet below Flight 66. Shortly thereafter, with Flight 66 level at 4000 feet (as cleared by ATC) the flight crew and the observer visually sighted the other aircraft, which then passed to the left and below Flight 66.

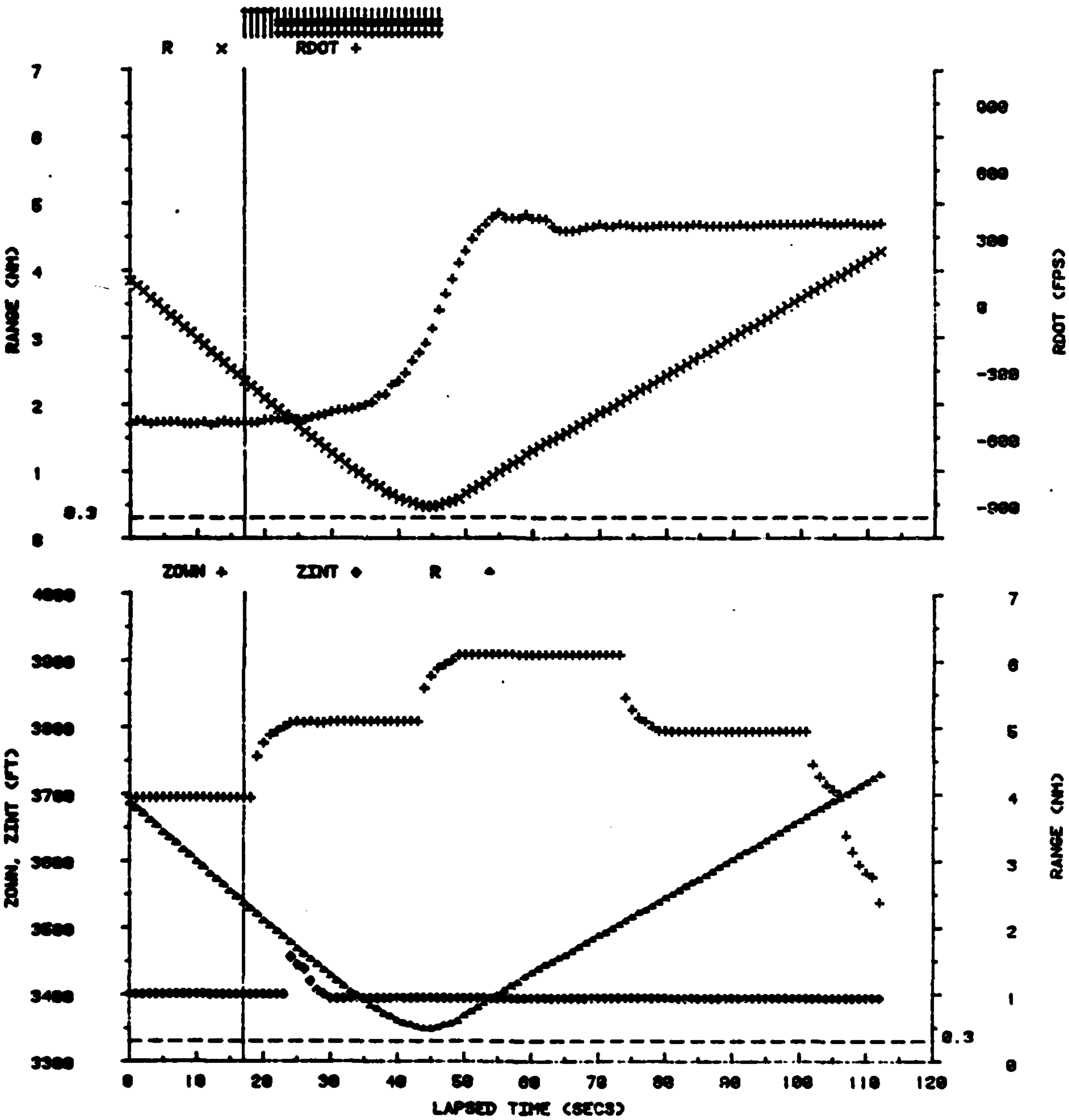
The observer felt that the system performed as he expected in this conflict situation and that the "DON'T DESCEND" resolution advisory was correct and would not have interferred with the flight crew duties. This advisory was classified as a "preventive" advisory inasmuch as Flight 66 was level and not descending at the time the "DON'T DESCEND" advisory was given. The observer did not feel that the traffic advisory was useful in this encounter. He felt that the resolution advisory was given sufficiently enough in advance to resolve the encounter.

The data plots confirm the observer's account with one exception. The recorded data shows that there was a five-second "CLIMB" advisory given before the "DON'T DESCEND" was given. This advisory was not seen by the observer, however the "DON'T DESCEND" advisories were observed on the IVSI. This may have been caused by a malfunction in the display system, however, inspection revealed no obvious failures, and the problem did not recur.


TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
140
120
100
80
60
40
25
20
0
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)


7
5
3
1
3
5
7


A
VMD
700
600
500
400
340
300
200
100
0
A, VMD (FT)
ZDOWN×
ZDINT◆
30
20
10
0
-10
-20
-30
-40
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZDWN +
ZINT ◆
R ◆
ZDWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

CASE 5

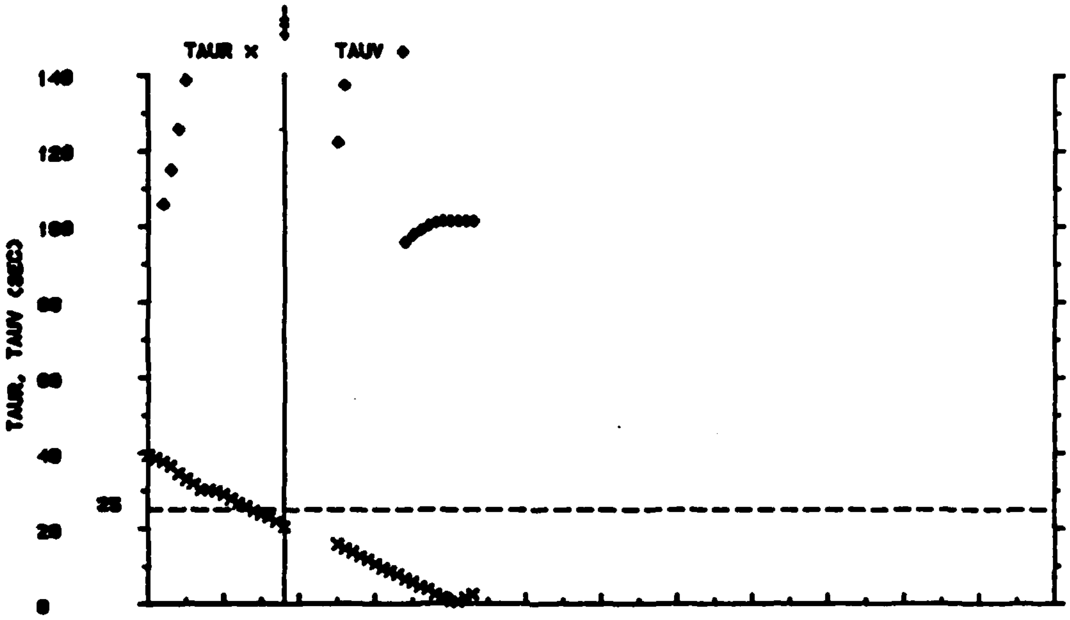
(Tape A011, Intruder 128) Don't Descend on Departure

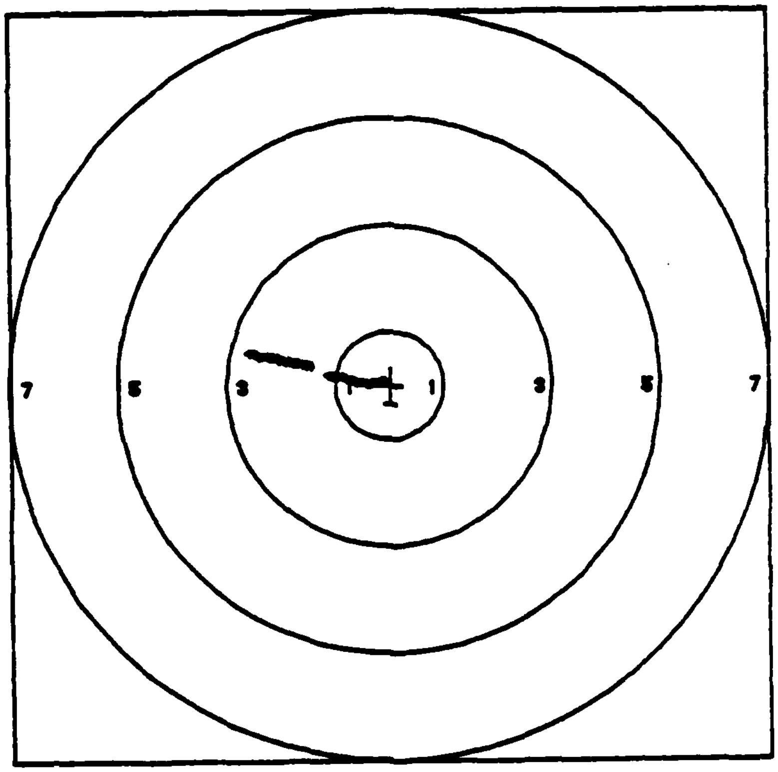
This low altitude advisory is only one second in duration and apparent occurred during the departure phase of flight. There are two anomolies in the recorded data:

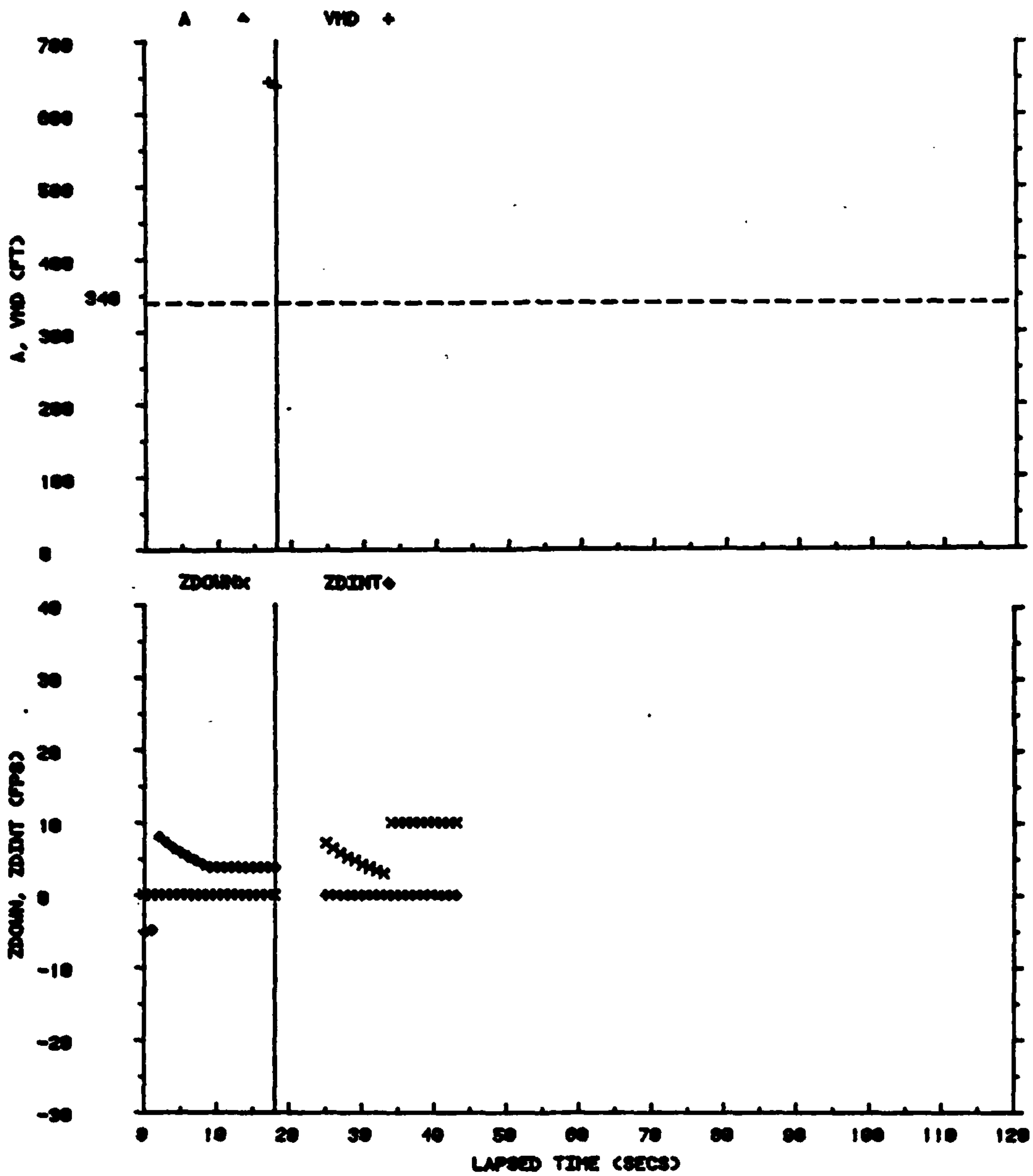
a. there is a six second data gap starting at the time the resolution advisory was generated. This gap represents a track drop and re-establishment of a new track under a different track number.

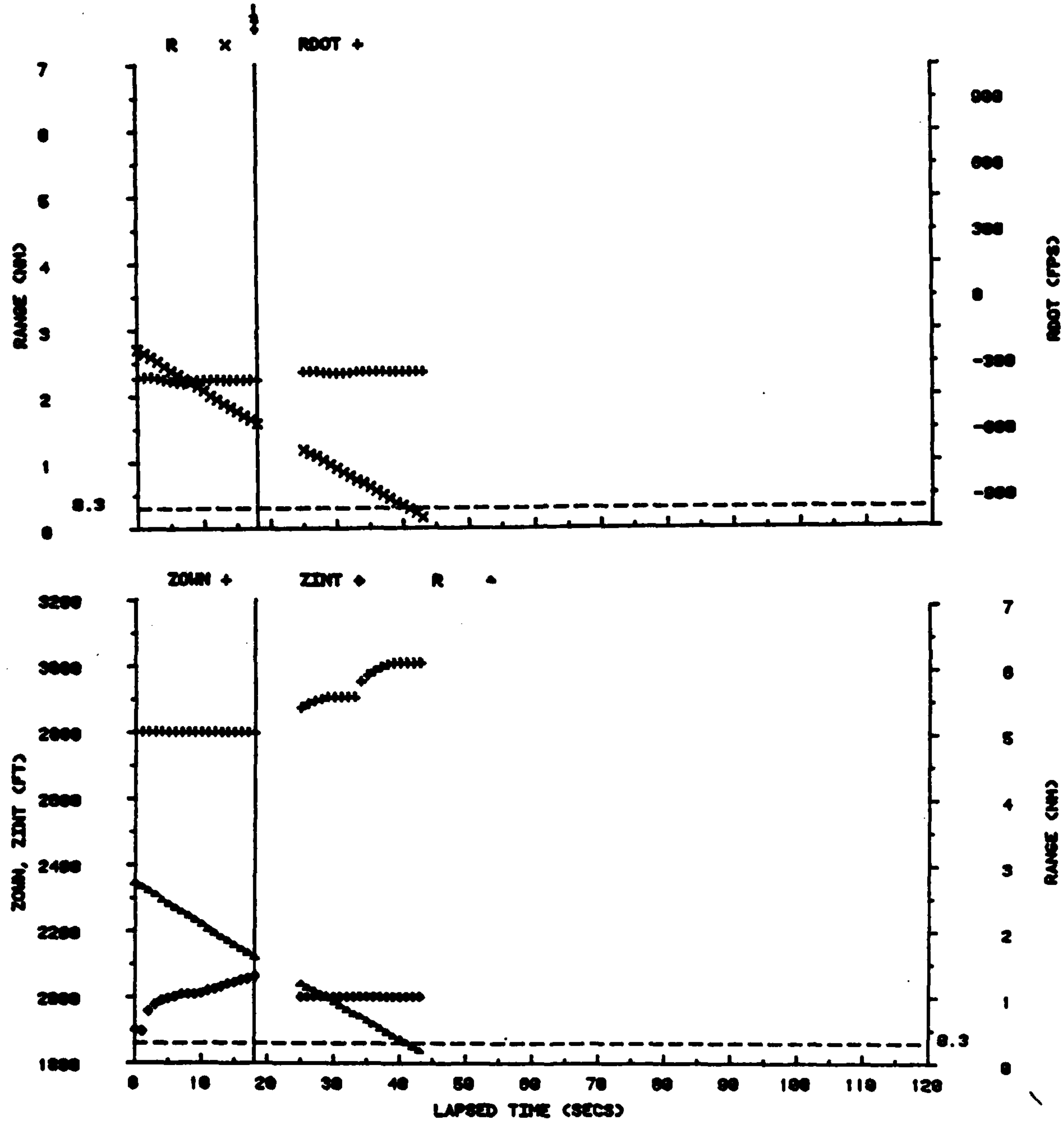
b. the five second minimum displayed advisory time was not met.

Subsequent to this encounter, the processor was removed from the aircraft and the software was reloaded.


TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
140
120
100
80
60
40
25
20
0


7
5
3
1
1
3
5
7


A
VHD
700
600
500
400
340
300
200
100
0
A, VHD (FT)
ZDOWN×
ZDINT◆
40
30
20
10
0
-10
-20
-30
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZDWN +
ZINT ◆
R ▲
ZDWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

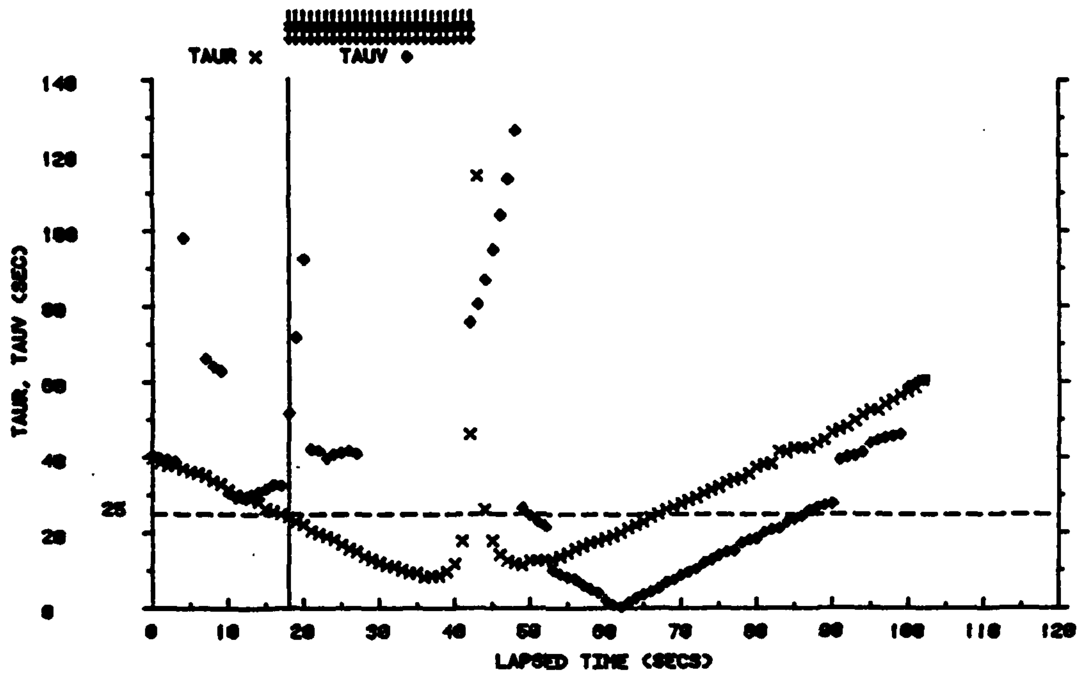
CASE 6

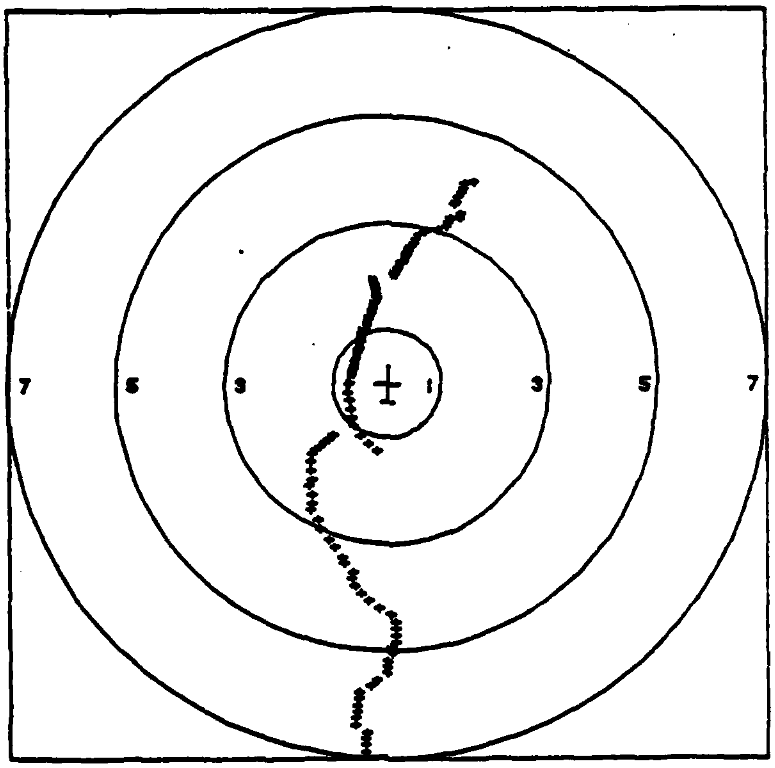
(Tape A014, Intruder 196) Don't Descend on Transition to Approach at Norfolk, Virginia, December 21, 1981

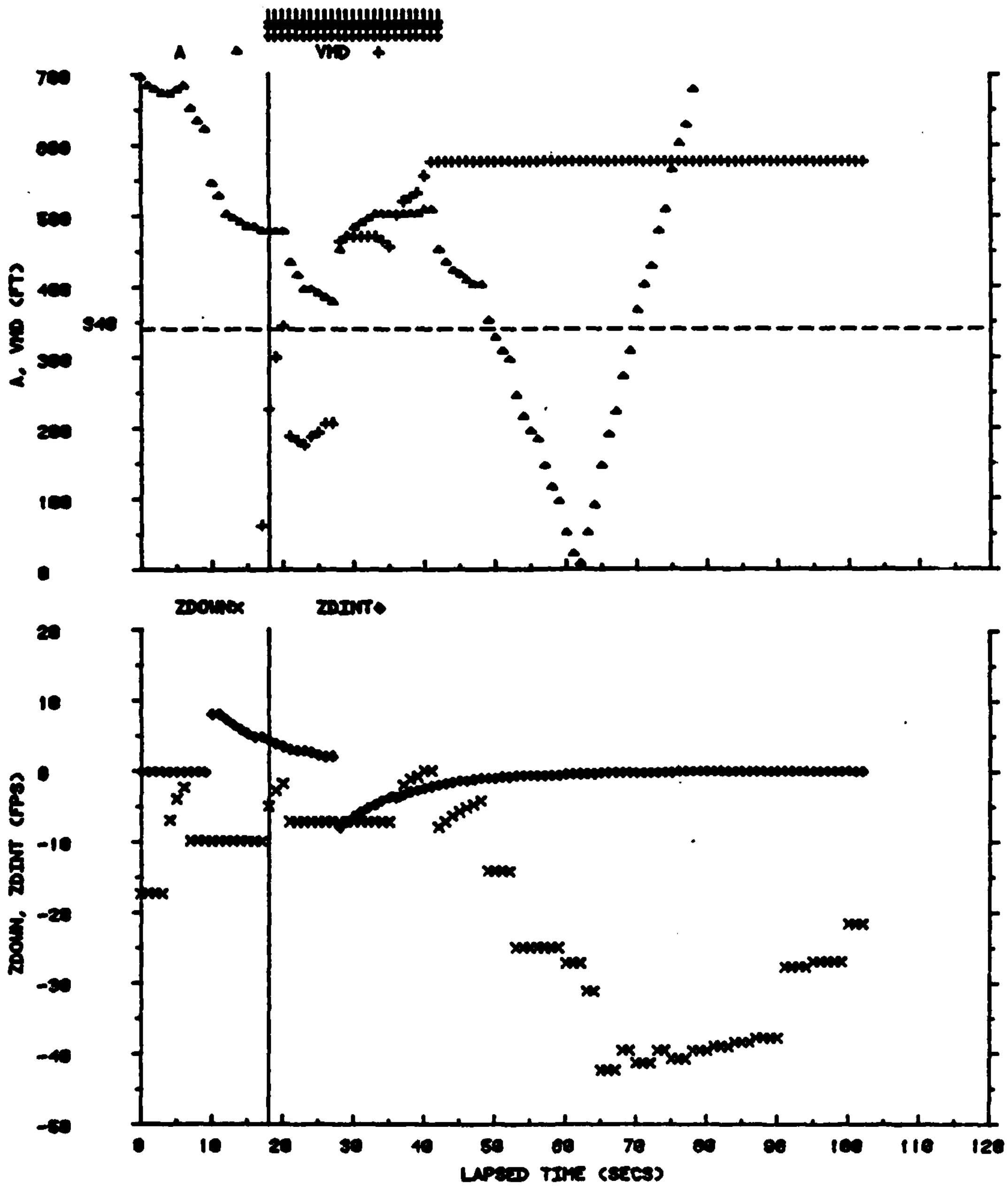
In the afternoon of December 21, 1981, the test aircraft, operating as Piedmont Flight 55, was approaching the Norfolk Regional Airport from the northeast for a straight-in landing on Runway 23. When Flight 55 was approximately 10 miles northeast of the airport, ATC advised it to stop its descent at 4000 feet because of right to left crossing traffic at 3500 feet. The flight crew and observer had previously sighted the intruder, a DC-7 that had just departed Norfolk Air Station.

The TCAS sounded the aural alert and gave a traffic advisory that first showed the intruder at 5 miles, 1 o'clock and 500 feet below the test aircraft. This target tracked toward the test aircraft and at approximately 2.5 miles a "DON'T DESCEND" resolution advisory was shown on the TCAS IVSI. The TCAS traffic display continued to provide position data that correlated to the actual positions of the aircraft. The DC-7 passed in front of and below the test aircraft, after which ATC permitted further descent for landing.

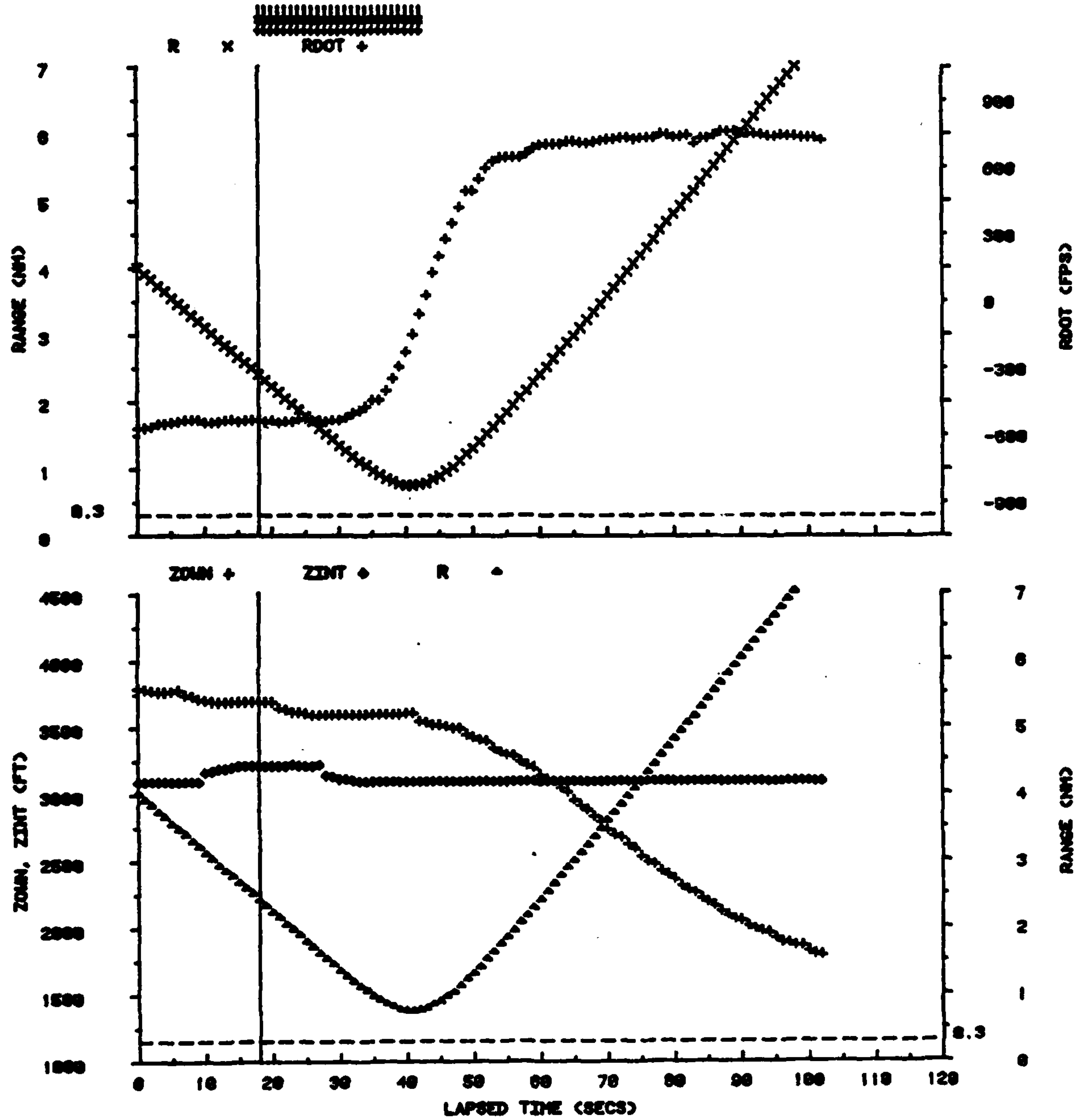
This encounter is quite typical of those observed during the evaluation. The two aircraft had visual signting of each other and ATC had issued advisories to both. The safe passage was accomplished by cooperative action of both pilots and ATC. The TCAS traffic advisory first appeared after the ATC advisory and showed the apparent true relationship of the two aircraft. The TCAS resolution advisory was compatible with the action taken by the flight crew and ATC. The observer felt that the TCAS would not have interfered with the normal duties of the flight crew.


TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
140
120
100
80
60
40
25
20
0
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)


7
5
3
1
3
5
7



A
VMD +
700
600
500
400
340
300
200
100
0
A, VMD (FT)
ZDOWN×
ZDINT◆
20
10
0
-10
-20
-30
-40
-50
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



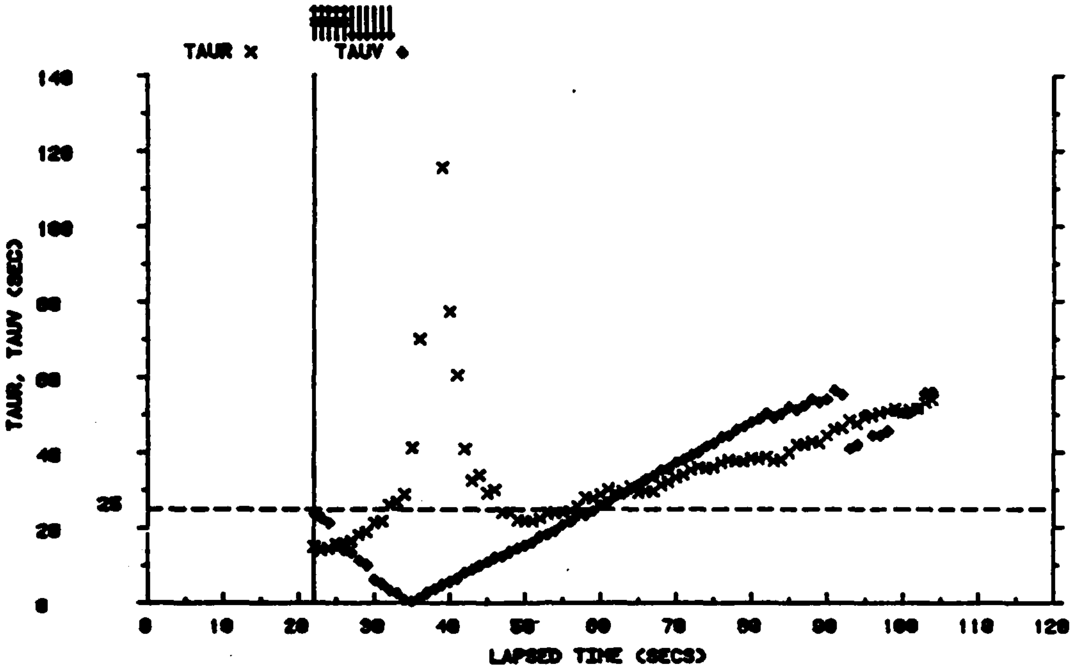
R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZDWN +
ZINT ◆
R ◆
ZDWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

CASE 7

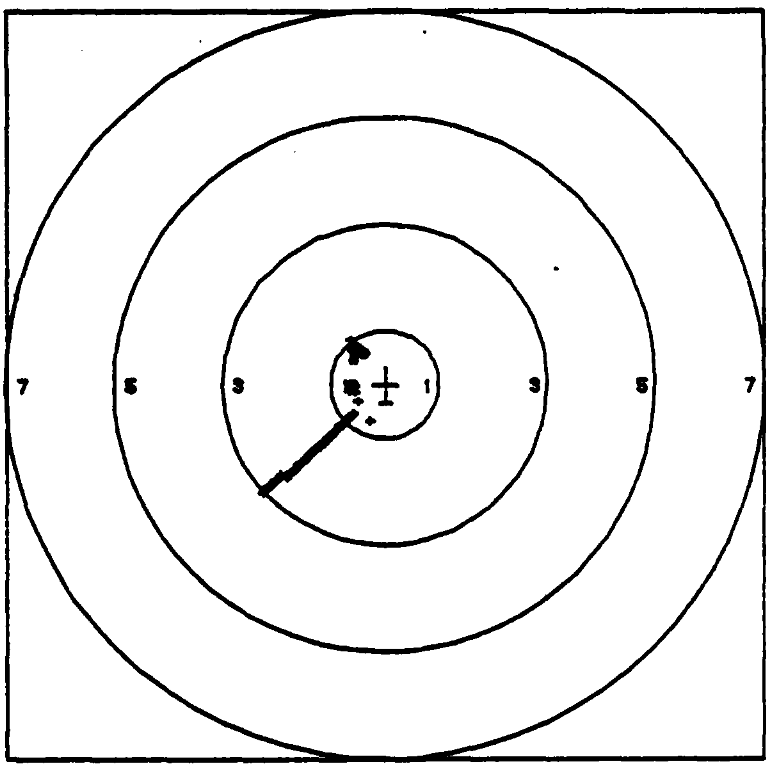
(Tape A015, Intruder 52) Transition Advisory (Don't Climb/ Descend) on Departure from Norfolk, Virginia, December 29, 1981

An ARINC observer and an FAA observer were aboard Piedmont Flight 50 from Norfolk, Virginia to Newark, New Jersey. Flight 50 had passed over Norfolk Naval Air Station and was approximately 6 miles northwest of the civil airport at Norfolk when departure control advised of traffic at 11 o'clock, 3 miles, in a left turn at 4,500 feet. Flight 50 was told to level at 4,000 feet. Flight 50 made visual contact on the called traffic. Alerted by the aural tone, an FAA observer noted a "Don't Climb" command which shortly transitioned to a "Descend" command on the TCAS modified IVSI. Traffic advisory information displayed on the TCAS CRT concurred with departure control. The display showed a target at 11 o'clock, 2 miles, 200 feet high that trailed down the left side, passed co-altitude with a virtually merged plot, descended in relative altitude to 1,200 feet below own aircraft, and left the scope at the 6 o'clock position. Departure control had called for and received further pilot verification of visual contact when a merged plot was observed. The traffic was identified as a relatively slow moving Navy C-1 radial-engined aircraft that made a left turn as Flight 50 passed down its right and continued its departure climb to the west.

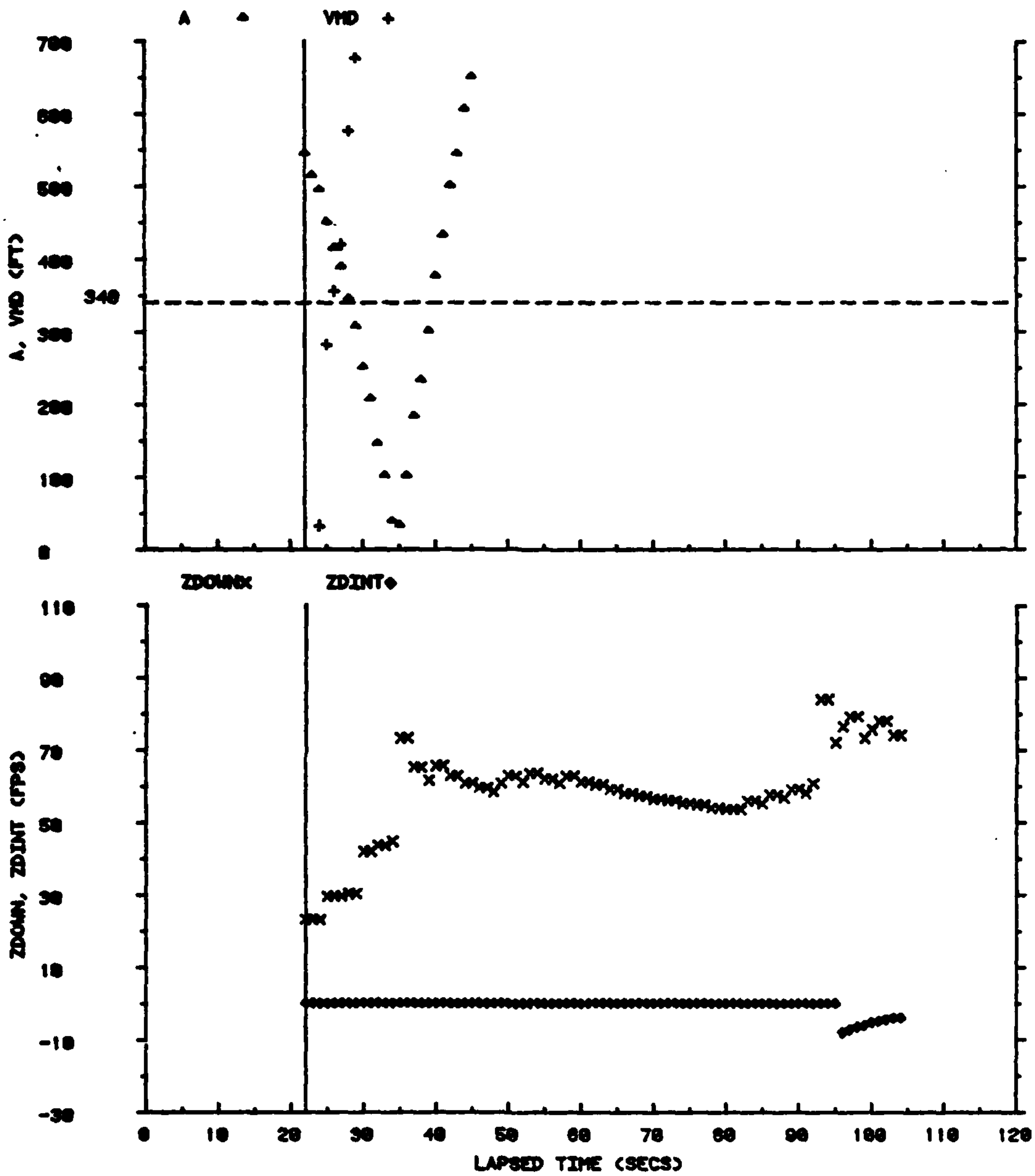
The TCAS commands and traffic information concurred closely with those of departure control. Both observers considered the commands would have been timely and correct had the situation not been resolved by departure control. In fact this situation evolved only because both aircraft had the other in sight and were cleared to maintain visual separation.



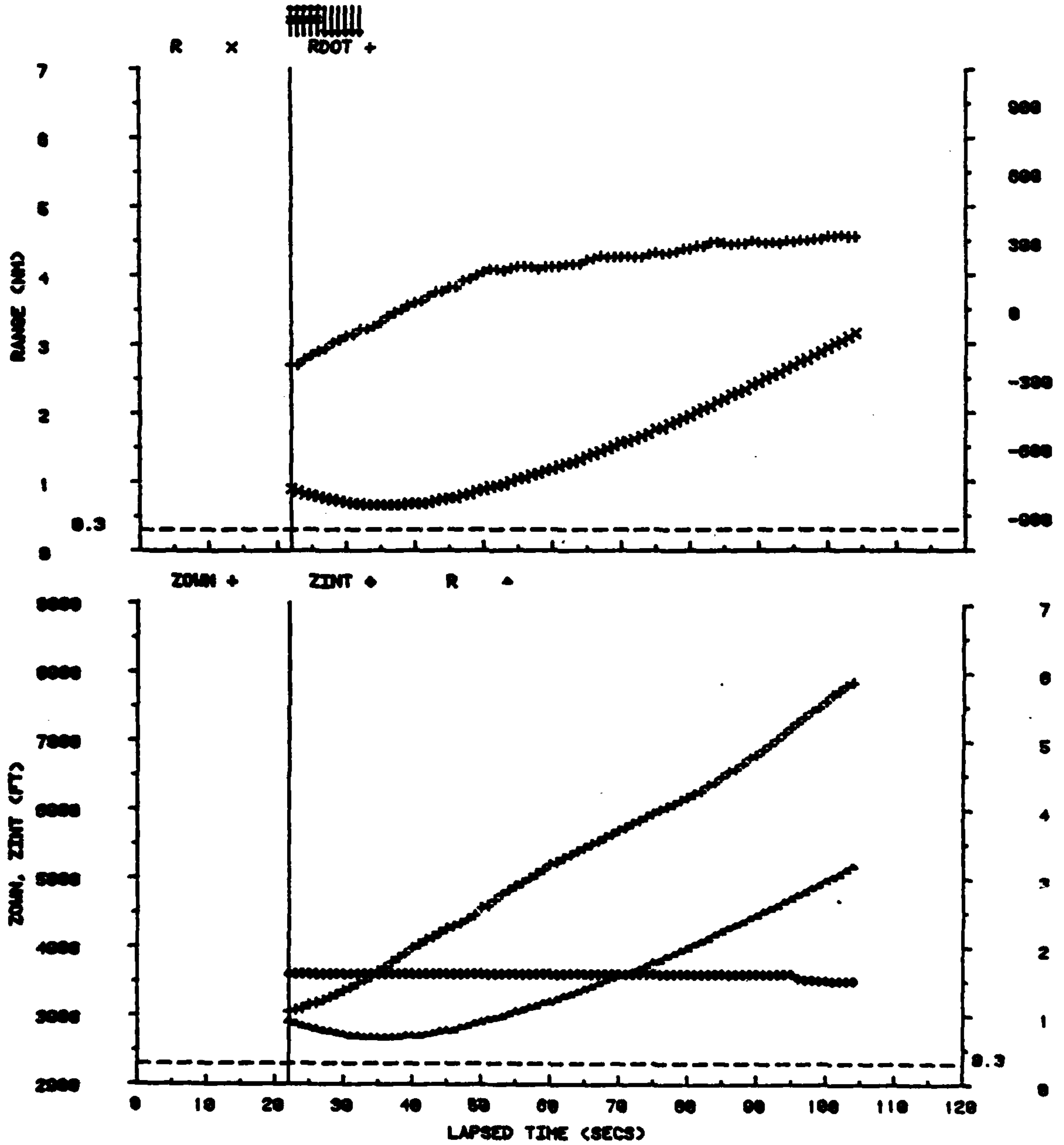
TAUR ×
TAUV ◆
140
120
100
80
60
40
25
20
0
TAUR, TAUV (SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
1
3
5
7



A
VMD +
700
600
500
400
340
300
200
100
0
A, VMD (FT)
ZDOWN×
ZDINT◆
110
90
70
50
30
10
-10
-30
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZOWN +
ZINT ◆
R ▲
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

CASE 8

Limit Descend on Approach to Charlotte, North Carolina, December 29, 1981

On the afternoon of December 29, 1981, an ARINC observer and an FAA observer were aboard Piedmont Flight 55 from Norfolk, Virginia to Charlotte, North Carolina. Flight 55 was cleared to descend to 3,000 feet while being vectored to final approach when 6 miles east of the Charlotte airport, approach control advised of traffic at 9 o'clock, probably low, with altitude readout yet to come. (Traffic was probably on departure from Charlotte.) Approach control advised that altitude of the traffic should be below 2,500 feet. The FAA observer heard the TCAS aural tone and noted a target on the TCAS CRT to right side of own aircraft 1,200 feet low with vertical separation decreasing to 700 feet as the target passed down right side of the display. Shortly after traffic advisory information was first displayed, a "Don't Descend Faster Than 500 FPM" command was displayed on the TCAS modified IVSI. A small commuter type aircraft was sighted by the crew and the ARINC observer at 9 o'clock, ½ mile over 5/00 feet below own aircraft.

Traffic advisory information and the command to limit the descent was considered timely, correct, and compatible with own action.

CASE 9

Transition Advisory (Don't Descend/Climb) on Approach
Norfolk Virginia, January 6, 1982

On the afternoon of January 6, 1982, ARINC and FAA observers were aboard Piedmont Flight 55 bound from Newark, New Jersey to Norfolk, Virginia. At 1:25 p.m. EST, Flight 55 was 15 miles north of Norfolk at 3,000 feet mean sea level (MSL). Norfolk approach control advised that Piedmont Flight 55 would be overtaking a Mooney at 1,500 feet. The flight crew advised that they had the traffic in sight 40 seconds later. Closing on the Mooney, Piedmont Flight 50 was then cleared to descend for approach to Runway 23. With the descent established a TCAS traffic advisory indicated a target at less than one mile, 500 feet below own aircraft. With a flight path that brought the descending Boeing 727 almost directly over the slower Mooney, TCAS issued a Resolution Advisory of "Do Not Descend" that transitioned to a command of "Climb".

CASE 10

Descend Advisory During Departure Transition to En Route, Washington, D.C., January 22, 1982

An ARINC observer was aboard Piedmont Flight 50 en route from Washington's National airport to Norfolk, Virginia. At approximately 1428Z (9:28 EST), six minutes after takeoff, Flight 50 was level at 10,000 feet mean sea level (MSL), turning south, and awaiting clearance to climb to filed en route altitude of 11,000 feet. TCAS displayed a target at 3 o'clock, just outside 2 miles, 1,100 feet above own aircraft. The target then showed a closure to 2 miles and a descent to 900 feet above own aircraft when a resolution advisory of Descend was indicated on the TCAS modified IVSI. With the intruder descending to 800 feet above and trailing to 6 o'clock the resolution advisory cleared. With Flight 50 in a climb to 11,000 feet the target tracked at 6 o'clock to 8 miles and disappeared from the TCAS CRT. No ATC call of traffic had been given. No sighting of the intruder was made by aircrew or observer.

CASE 11

Multiple Transitions - En Route Charlotte, North Carolina, January 27, 1982

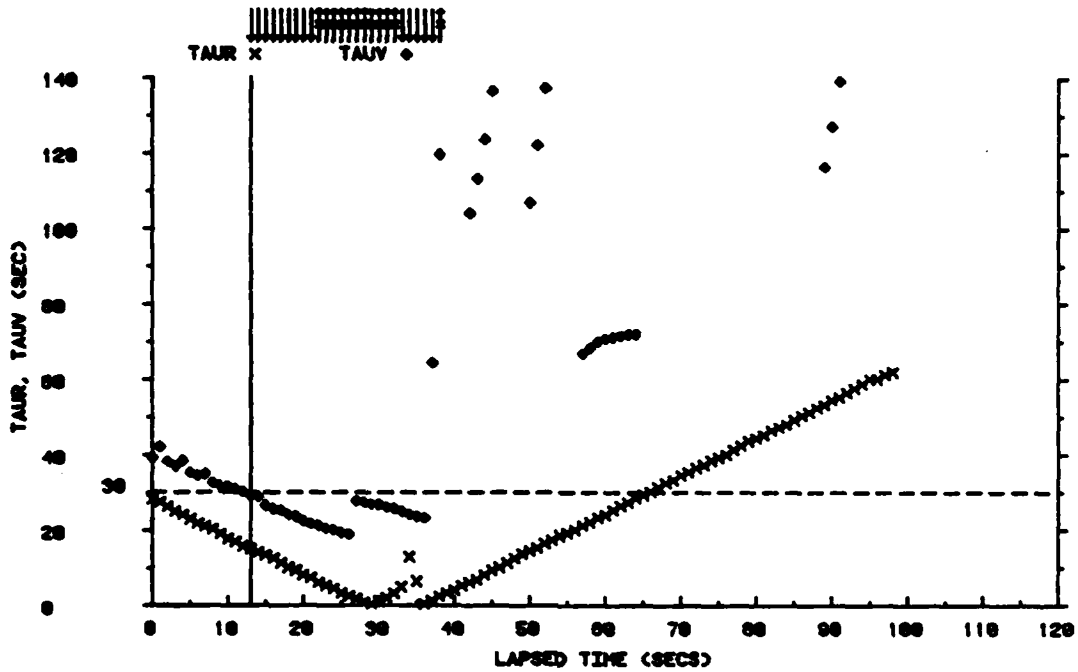
On the afternoon of January 27, 1982, the test aircraft operated as Piedmont Flight 55 between Norfolk, Virginia and Charlotte, N.C., with an FAA observer aboard. Flight 55 was level at FL260 in visual conditions. The observer noticed a traffic advisory on an intruder at the 10 o'clock position, range greater than 4 miles, and 1,100 feet above the test aircraft. Subsequent traffic information showed the intruder crossing from left to right with the vertical separation decreasing from 1100 to 900 feet. No ATC advisory was given.

The FAA observer called the flight crew's attention to the intruder, howerver the flight crew did not maneuver to increase separation between the aircraft.

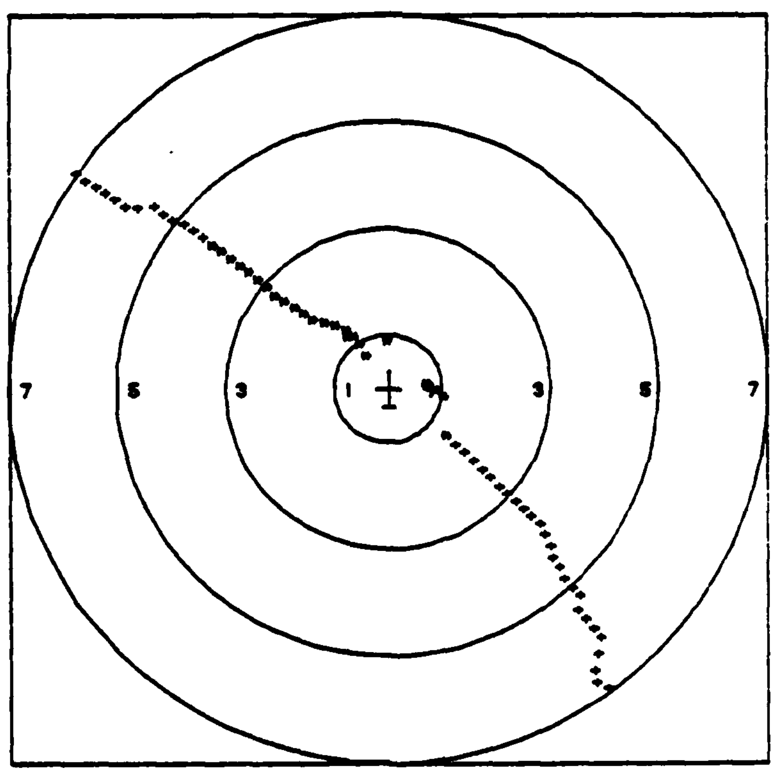
At a range of 4 miles, the TCAS gave a "DESCEND" advisory, followed by a "DON'T CLIMB", followed by a "DESCEND" and then followed by a "DON'T CLIMB".

The observer felt that the traffic information was valuable especially since no ATC advisory was issued. The flight crew did not deviate from their altitude, but did requrest the TCAS minimum range and minimum altitude information from the observer. The observer and flight crew both felt that the "DESCEND" resolution advisory was unnecessary and in actual fact the flight crew did not maneuver the aircraft.

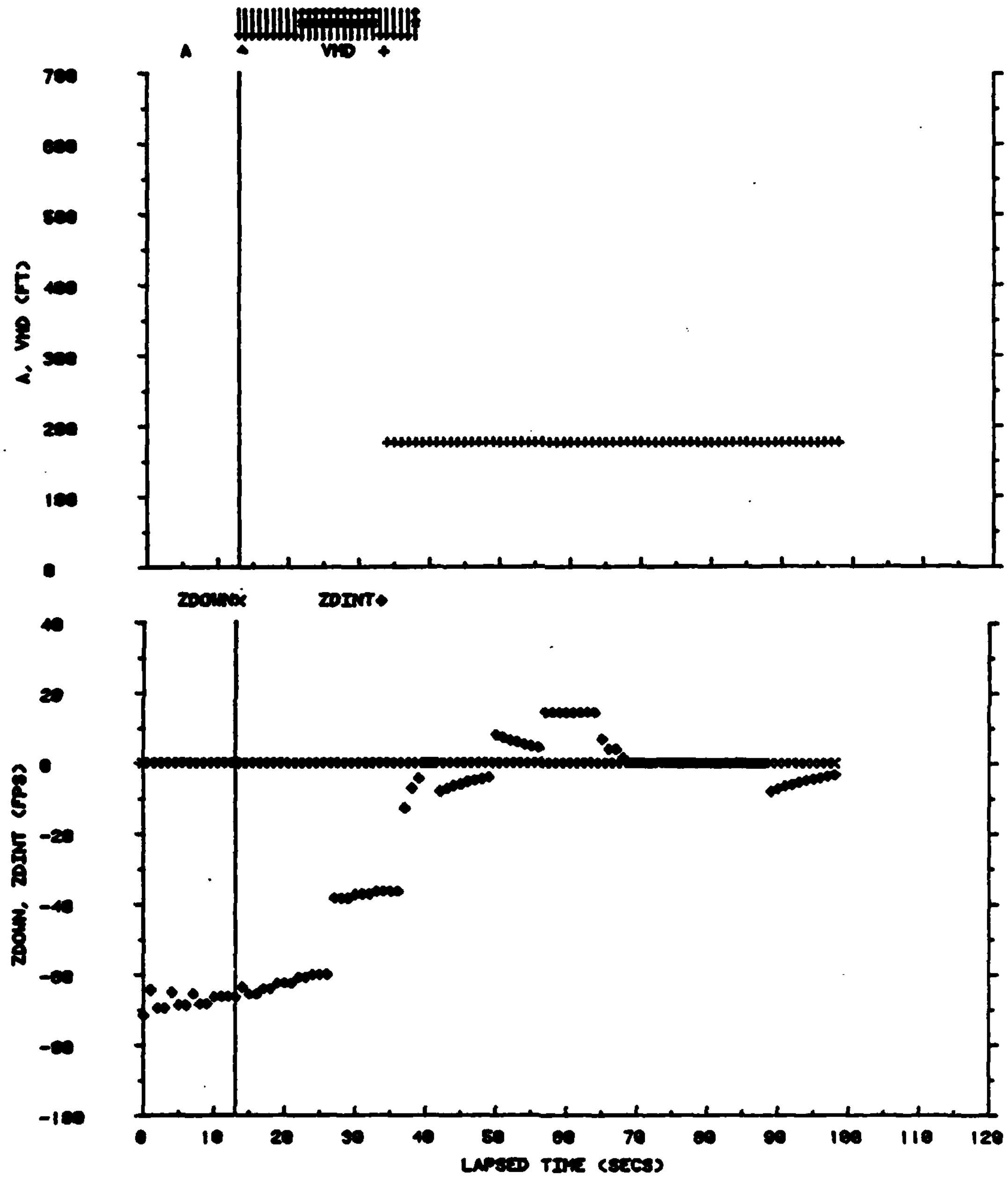
The recorded data confirms the observer record and shows that the intruder passed .6 mile to the right front of the test aircraft with 900 feet of altitude separation.



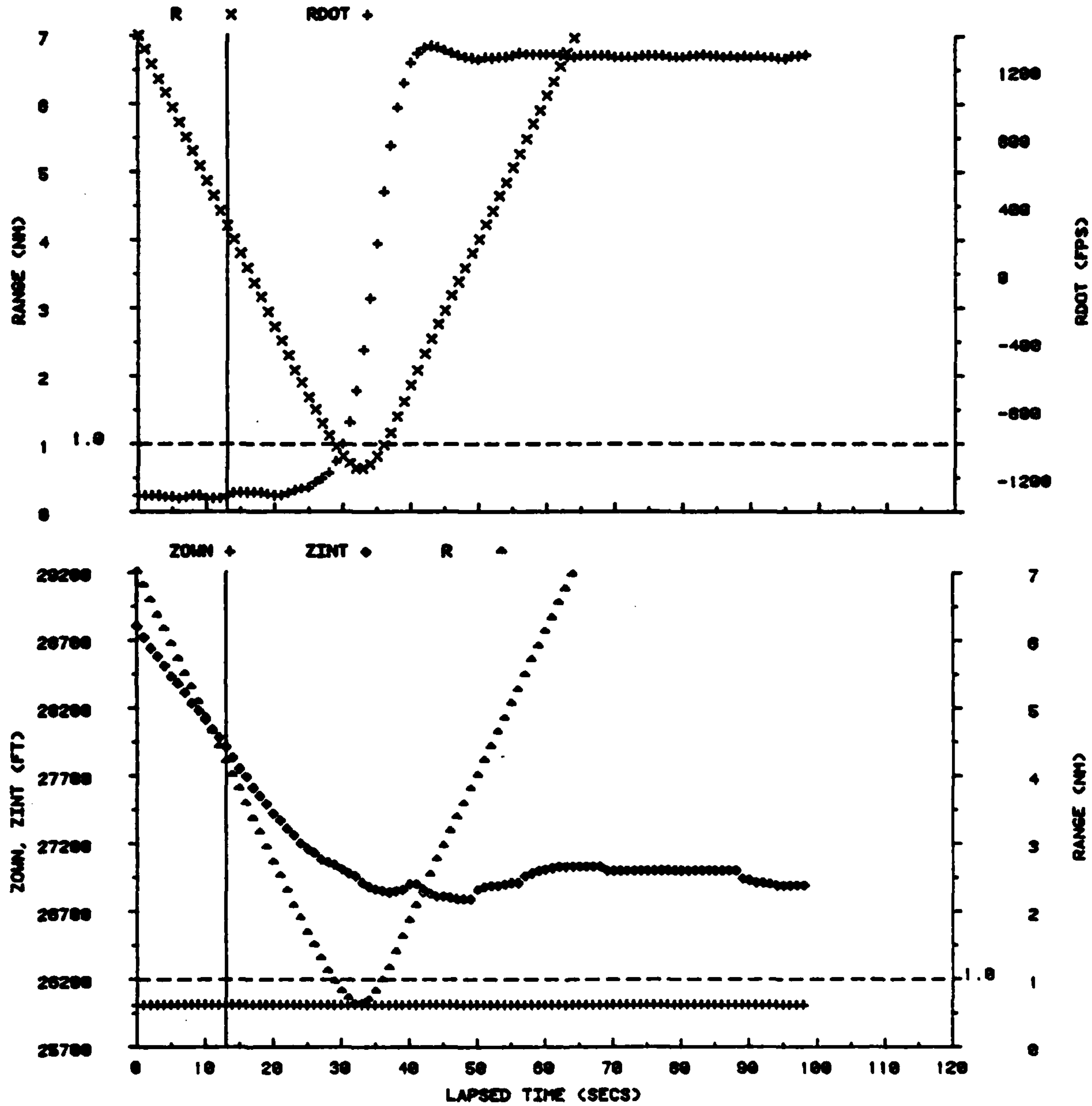
TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
140
120
100
80
60
40
30
20
0
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
1
3
5
7



A
VMD
700
600
500
400
300
200
100
0
A, VMD (FT)
ZDOWN×
ZDINT◆
40
20
0
-20
-40
-60
-80
-100
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

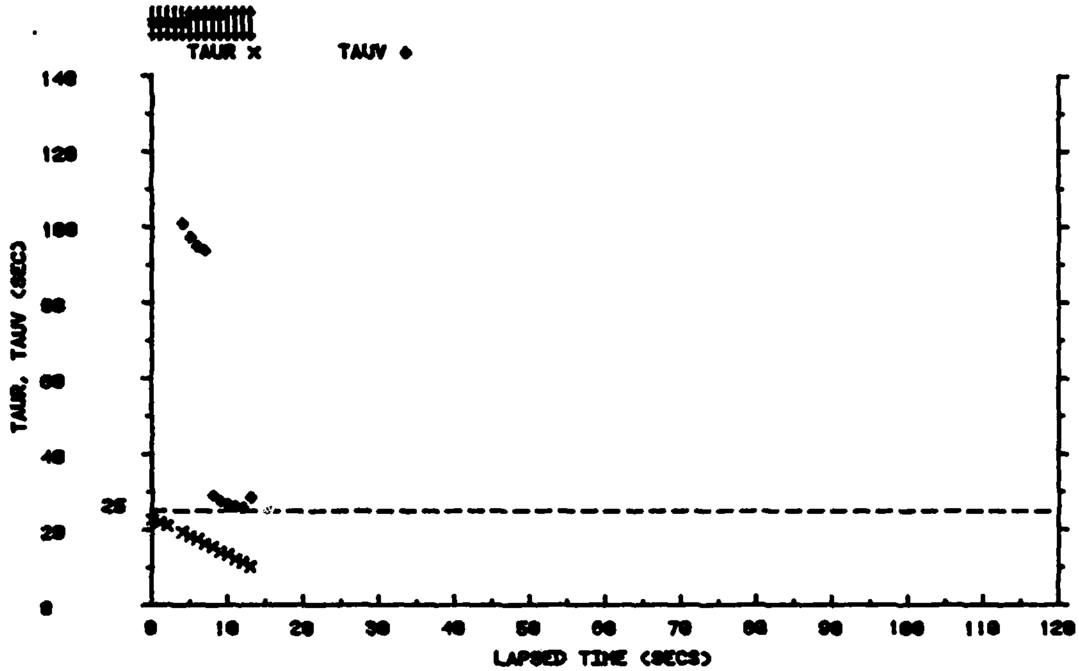

R ×
RDOT +
RANGE (NM)
RDOT (FPS)
7
6
5
4
3
2
1
0
1.0
1200
800
400
0
-400
-800
-1200
ZOWN +
ZINT ◆
R ▲
ZOWN, ZINT (FT)
RANGE (NM)
28200
28700
28200
27700
27200
26700
26200
25700
1.0
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

CASE 12

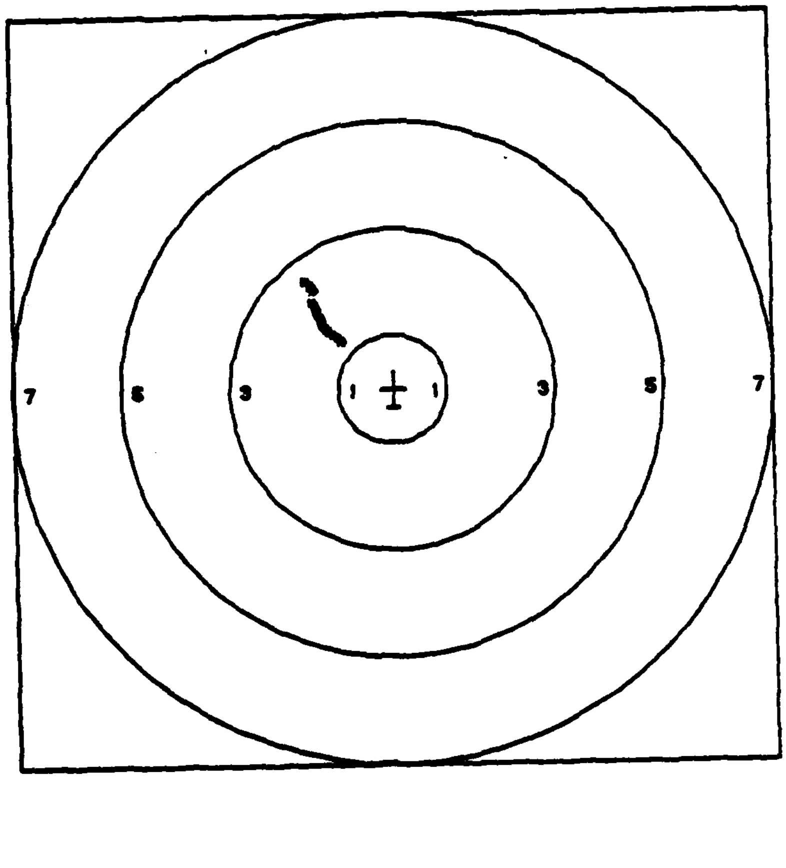
(Tape A023, Intruder 141) Transitioning Advisories of Traffic on Approach to Parallel Runways

This encounter was unobserved, however data shows it occurred while on approach to Charlotte, N.C.

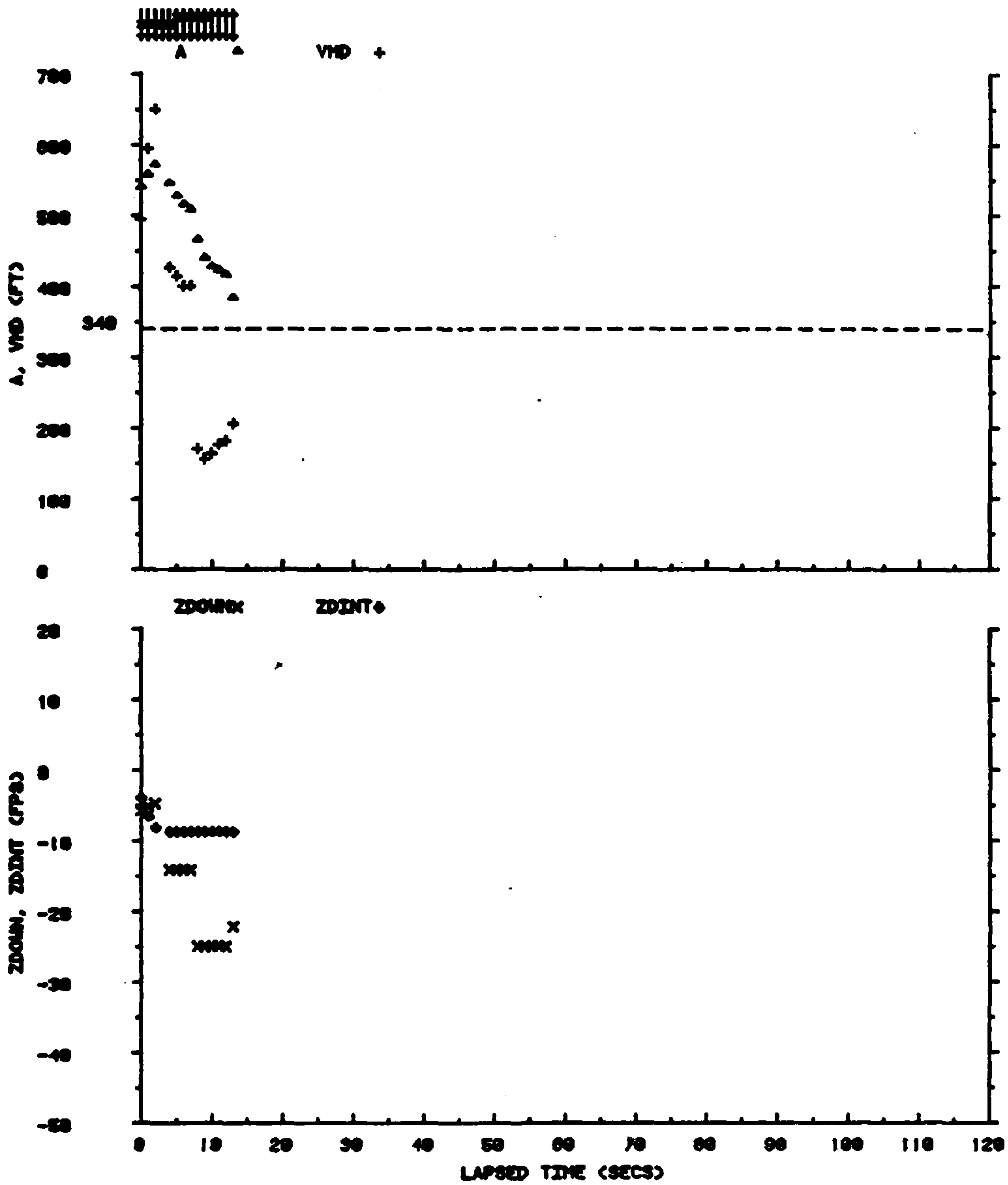
There is no precursor traffic advisory which would be consistant with one or both aircraft turning to align with the runway for landing. The test aircraft is descending at a higher rate than the intruder, and is closing in range, which indicates an overtake geometry.

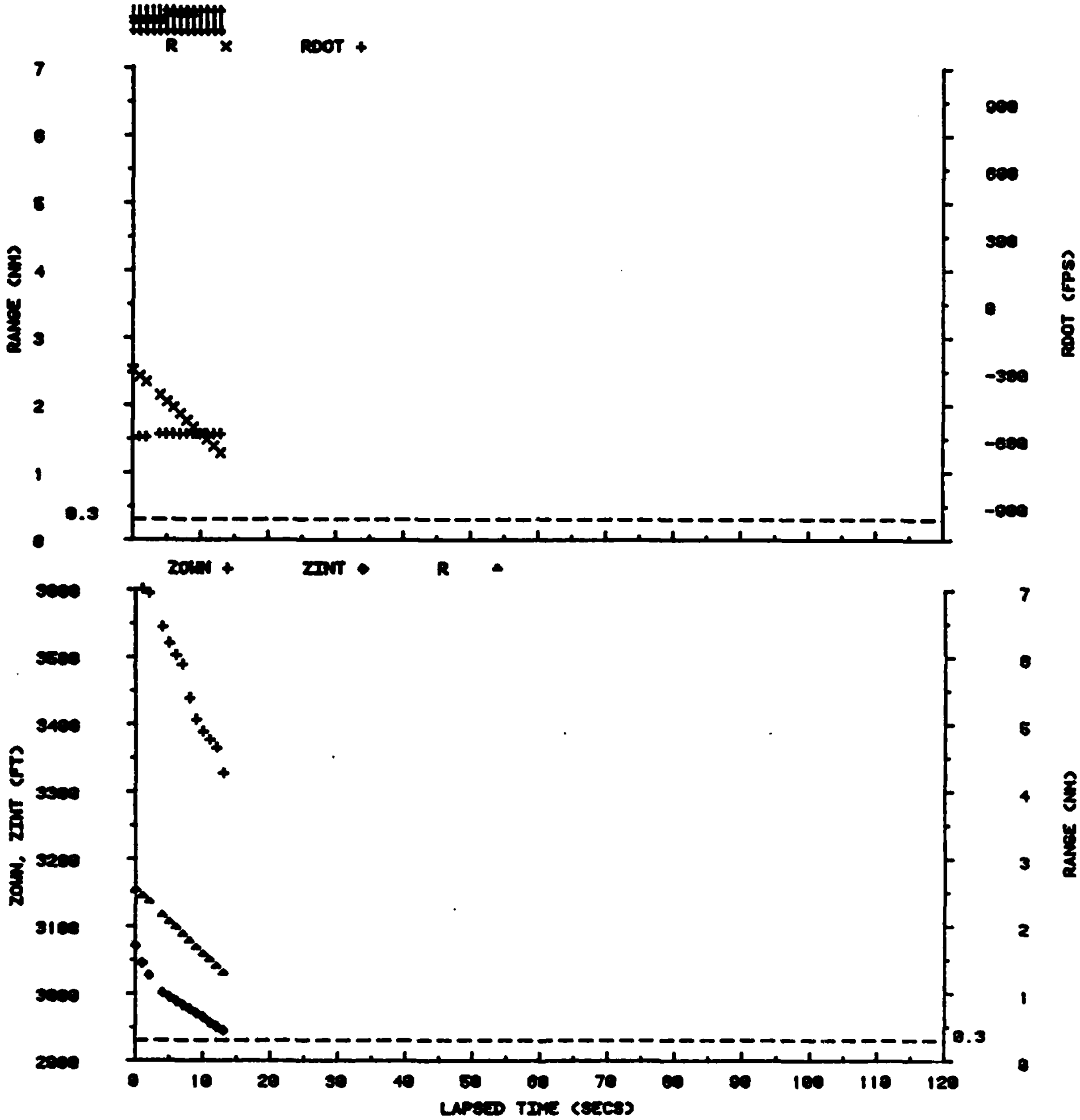


TAUR x
TAUV ◆
TAUR, TAUV (SEC)
LAPSED TIME (SECS)



7
5
3
1
1
3
5
7

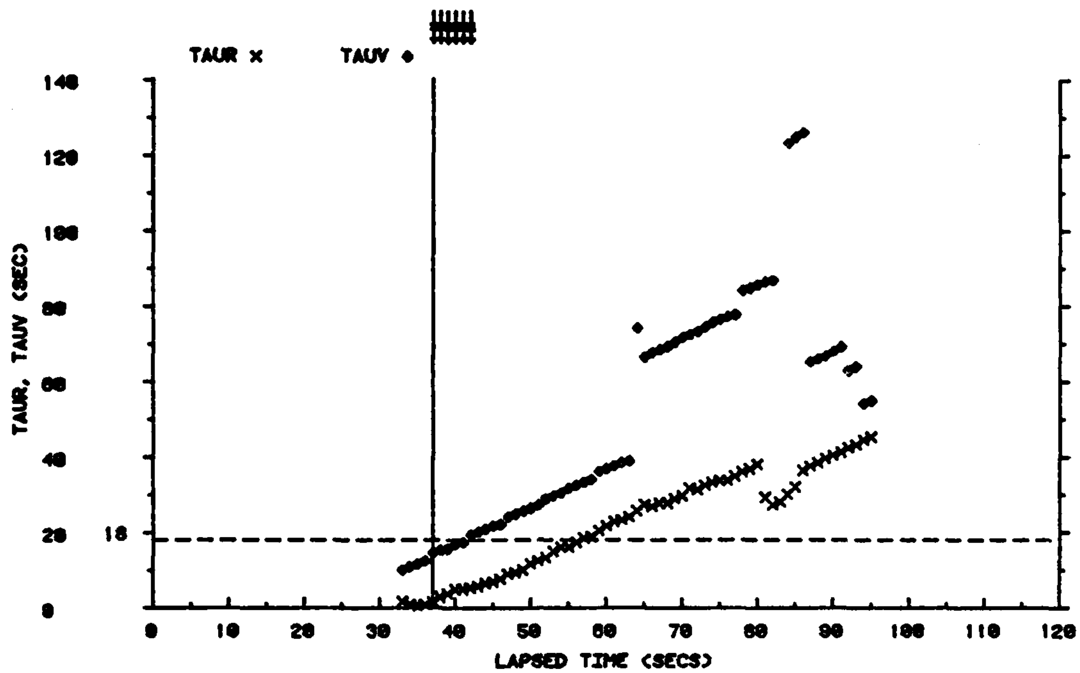

A
VHD +
700
600
500
400
340
300
200
100
0
A, VHD (FT)
ZDOWN×
ZDINT◆
20
10
0
-10
-20
-30
-40
-50
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)


R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZDWN +
ZINT ◆
R ▲
ZDWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

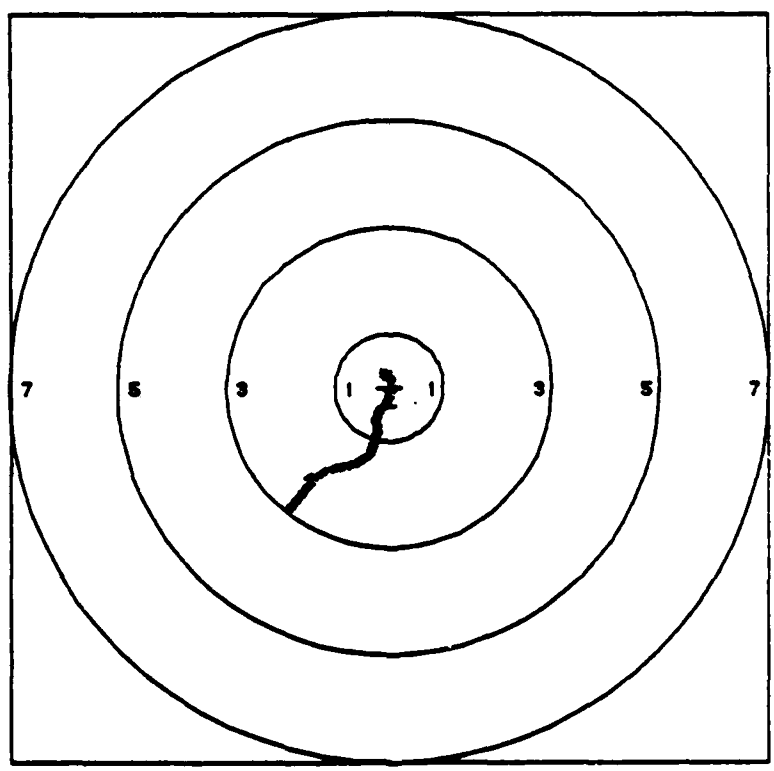
CASE 13

(Tape A-25, Intruder 203) Don't Descend on Intruder on the Ground on Takeoff

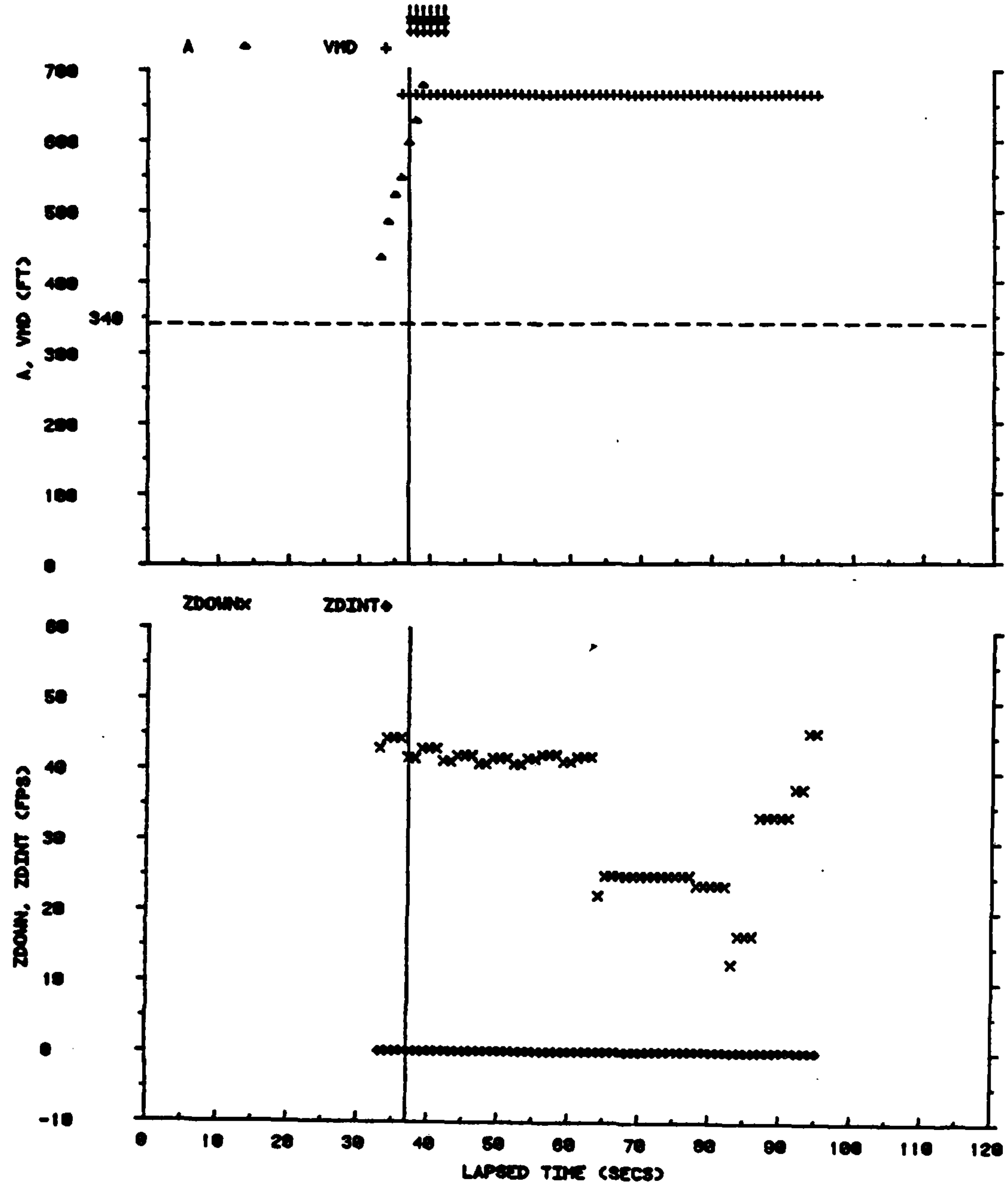
The altitudes, tracks, and rates associated with this encounter lead to the conclusion that this is a ground level intruder. The intruder is level at 700 feet, the test aircraft is climbing at rates that coorespond with initial climb, acceleration for flap retraction and subsequent climb, and the minimum range of 0.1 mile suggests an aircraft on a taxiway near the runway.



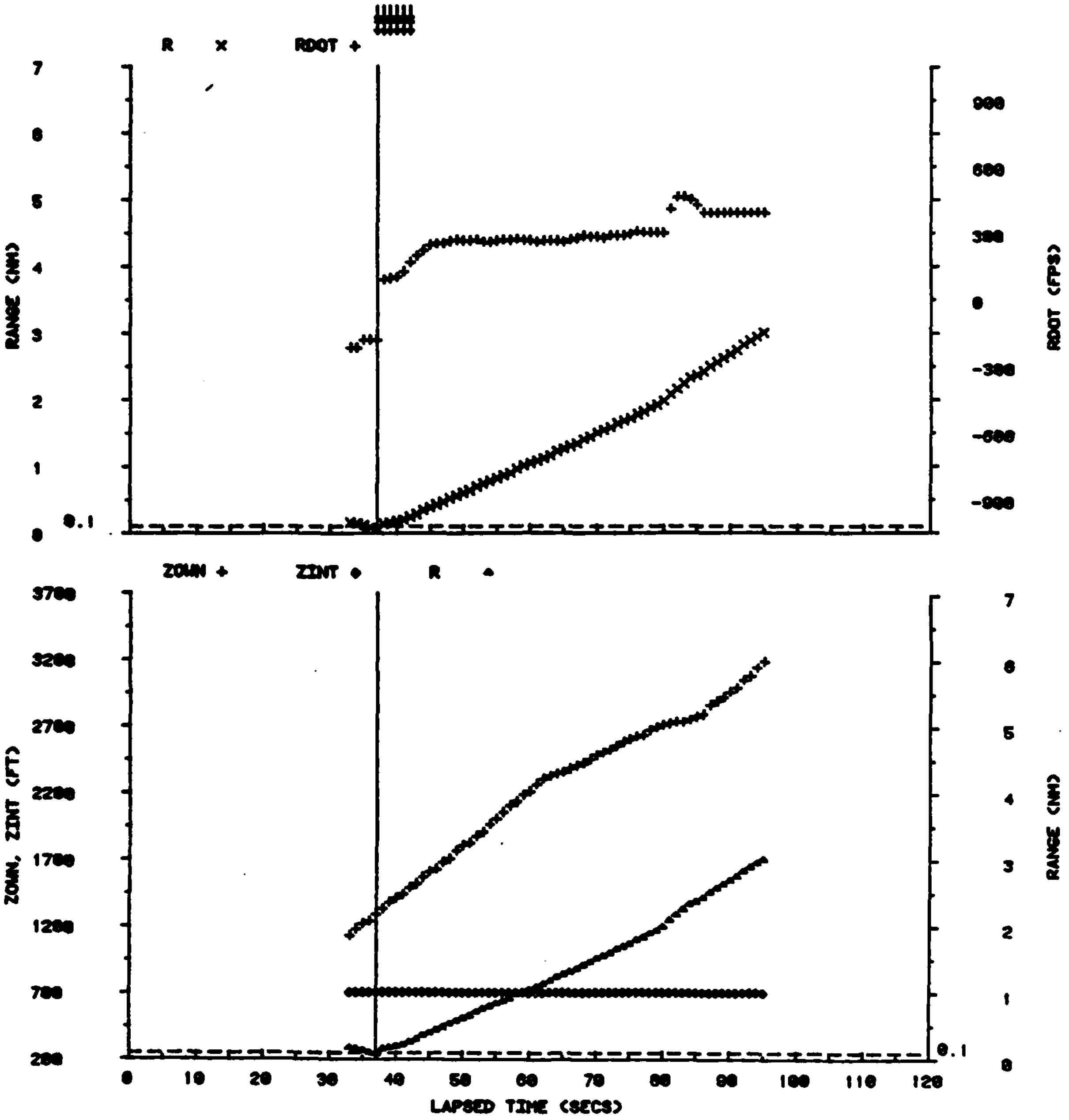
TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
140
120
100
80
60
40
20
0
18
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
1
1
3
5
7



A
VMD
700
600
500
400
340
300
200
100
0
A, VMD (FT)
ZDOWN
ZDINT
60
50
40
30
20
10
0
-10
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

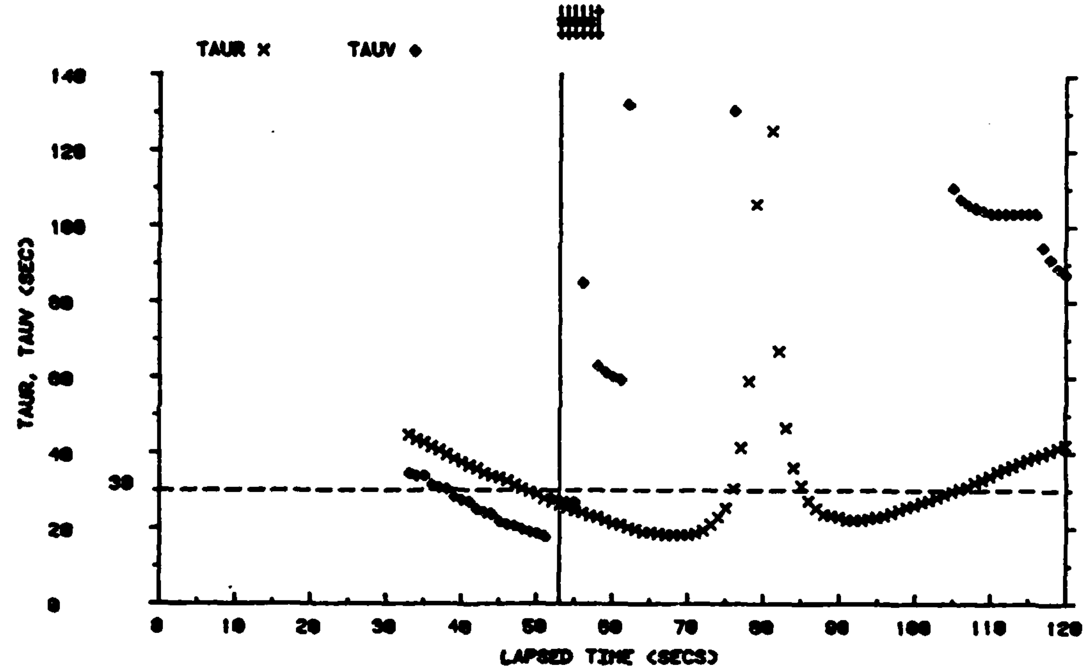


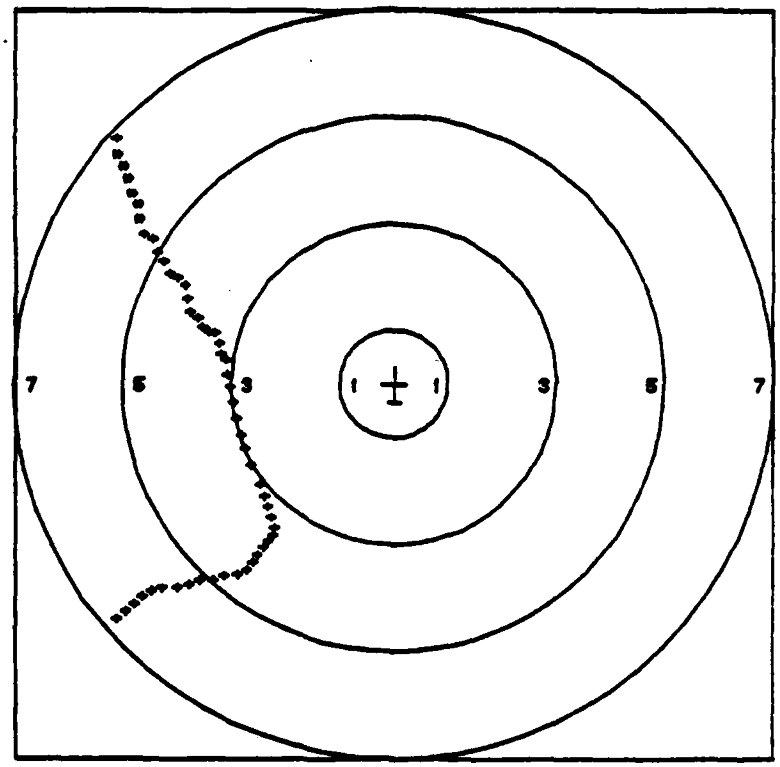
R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.1
ZOWN +
ZINT ◆
R ◆
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

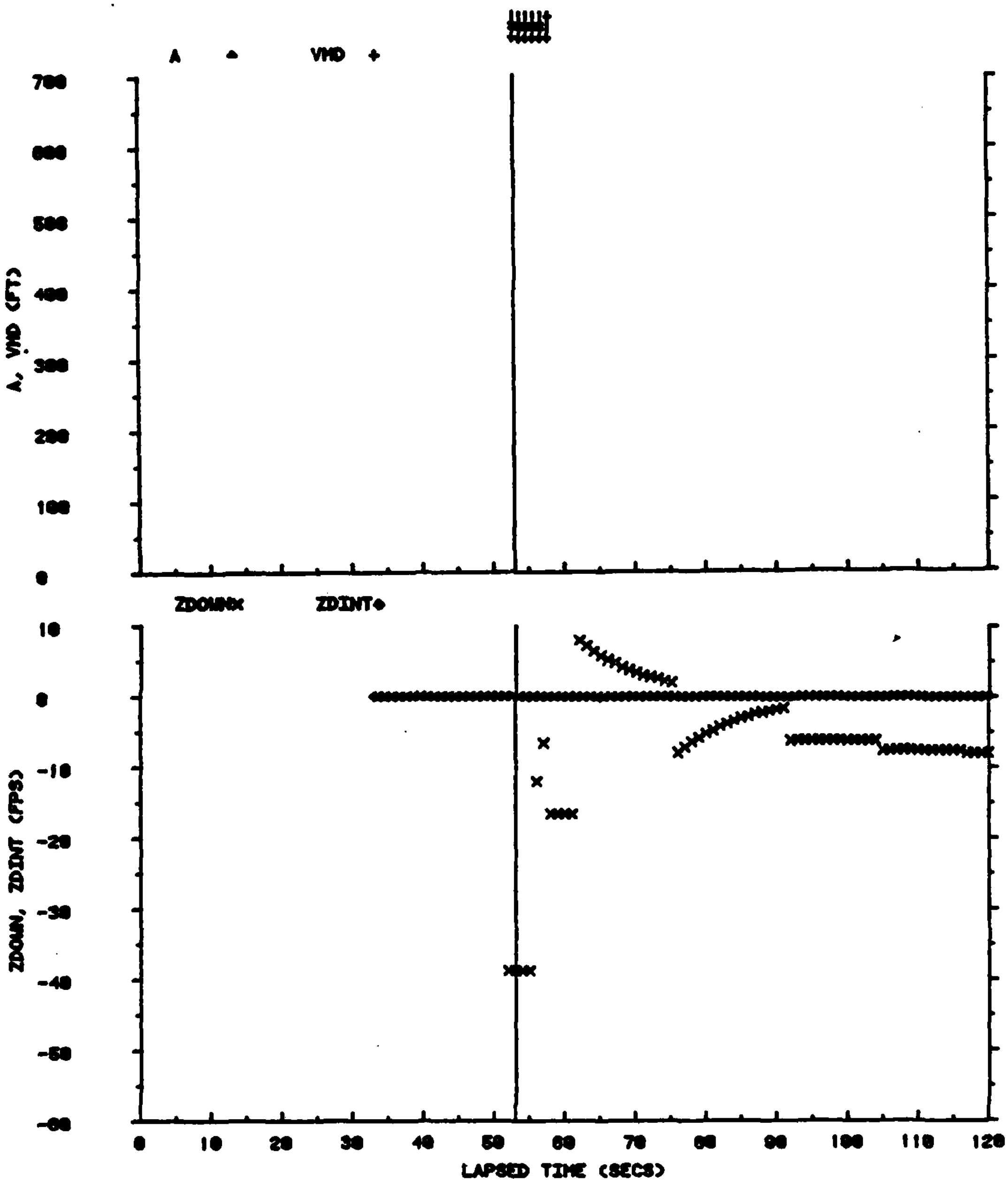
CASE 14

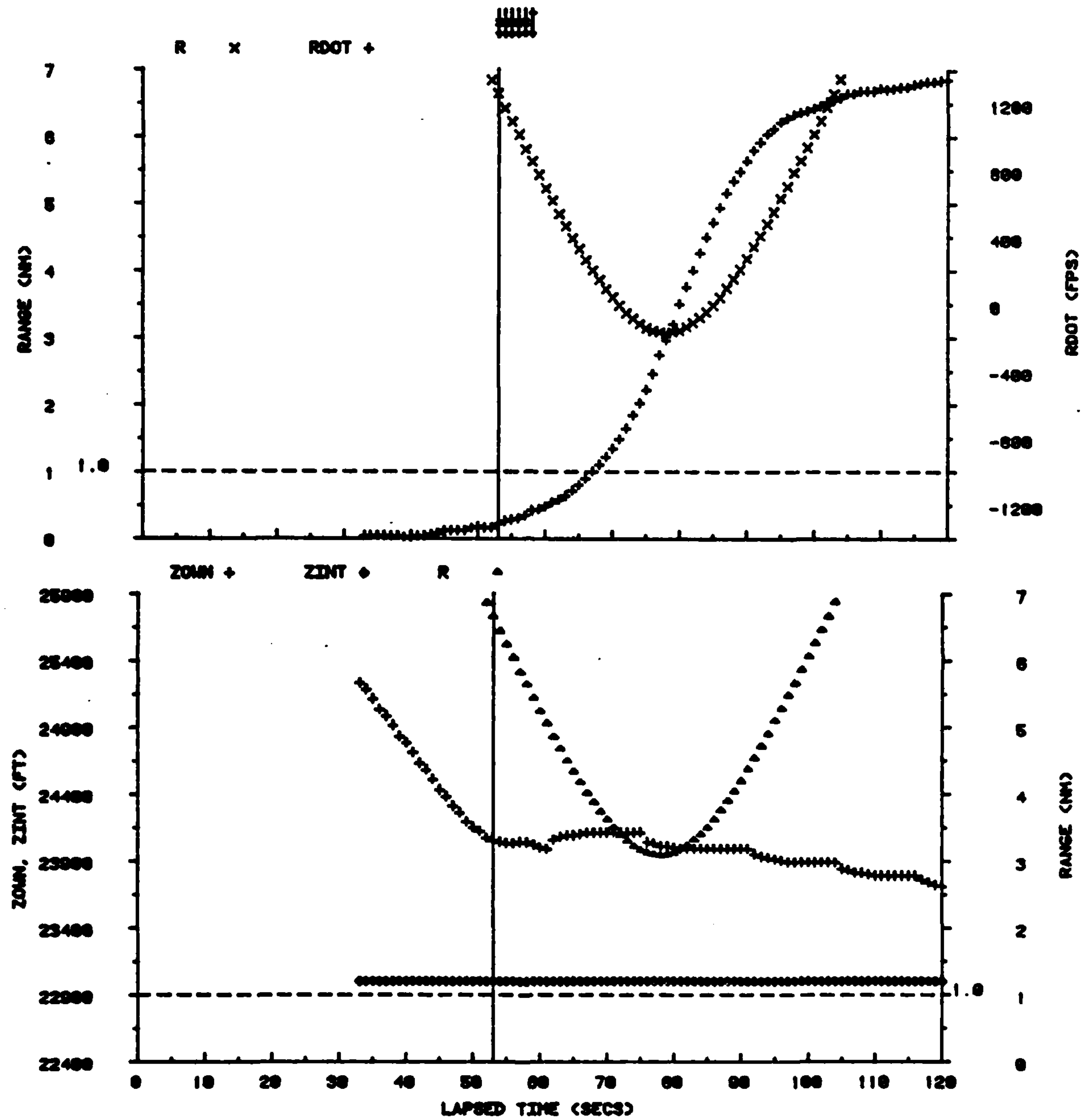
(Tape A025, Intruder 131) Transitioning Negative Advisories Don't Descend/Limit Descend (500 FPM) on Level En Route Intruder Below

During this encounter the intruder was level at 23,000 feet. Own aircraft was descending from above 25,000 feet and track was stopped at approximately 23,700 feet. Own aircraft did level and moderate its descent in a manner compatible with TCAS advisories. Minimum range was 3 miles.


TAUR ×
TAUV ◆
140
120
100
80
60
40
30
20
0
TAUR, TAUV (SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)


7
5
3
1
1
3
5
7


A
VMD
700
600
500
400
300
200
100
0
A, VMD (FT)
ZDOWN×
ZDINT◆
10
0
-10
-20
-30
-40
-50
-60
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

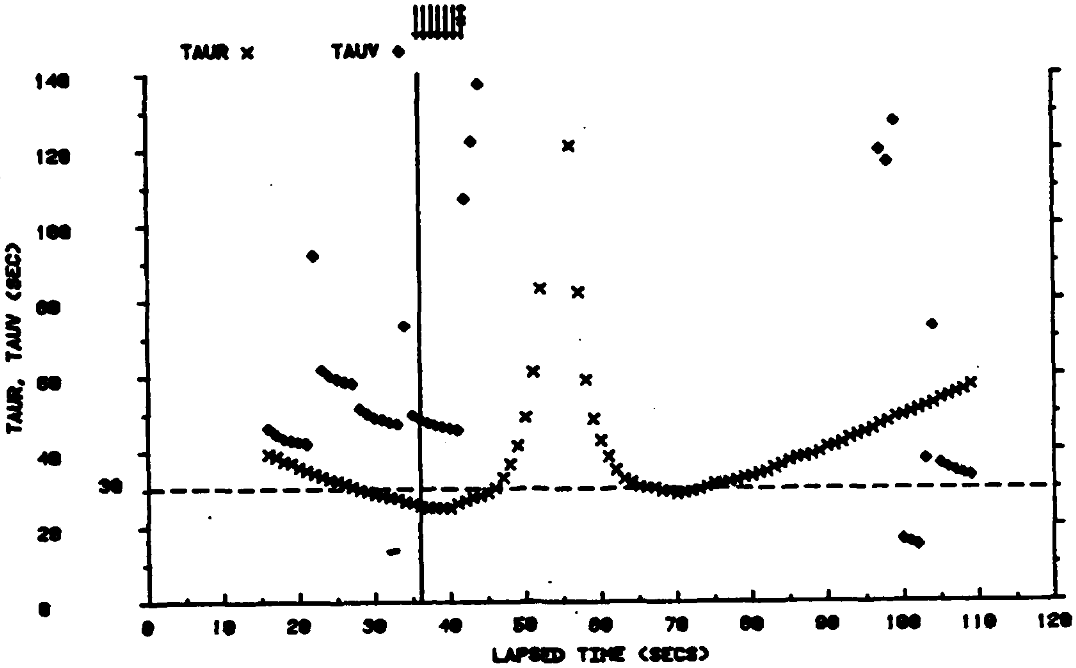

R ×
RDOT +
RANGE (NM)
RDOT (FPS)
1.0
ZOWN +
ZINT ◆
R ▲
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

CASE 15

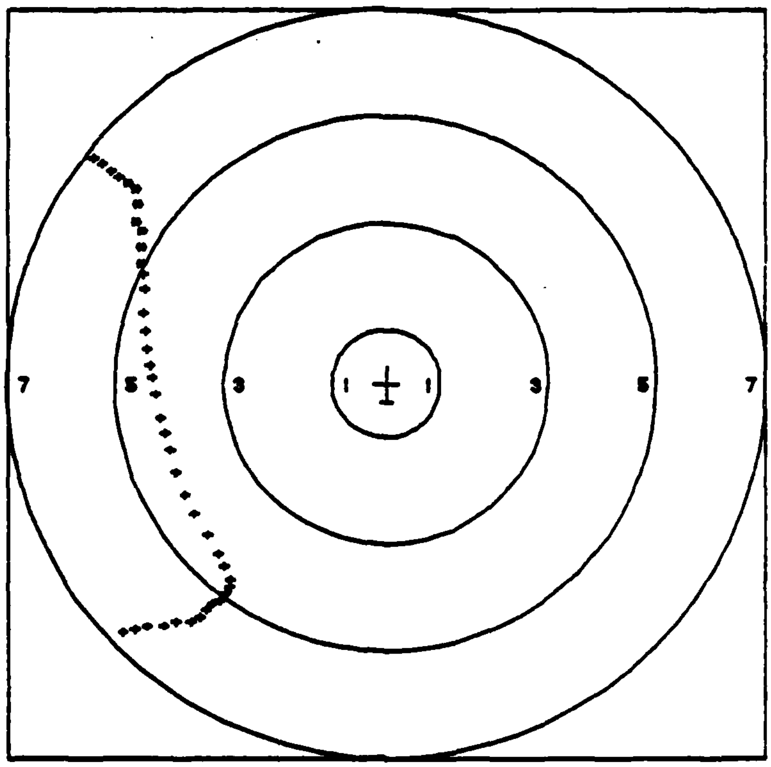
(Tape A027, Intruder 169) Transistion on Airborne Intruder
En Route

In this encounter, own aircraft is level at 25,000 feet and the intruder has apparently been cleared to descend to 26,000 feet. A change in heading allows passage of the intruder, approximatley 4½ miles left of own aircraft course.

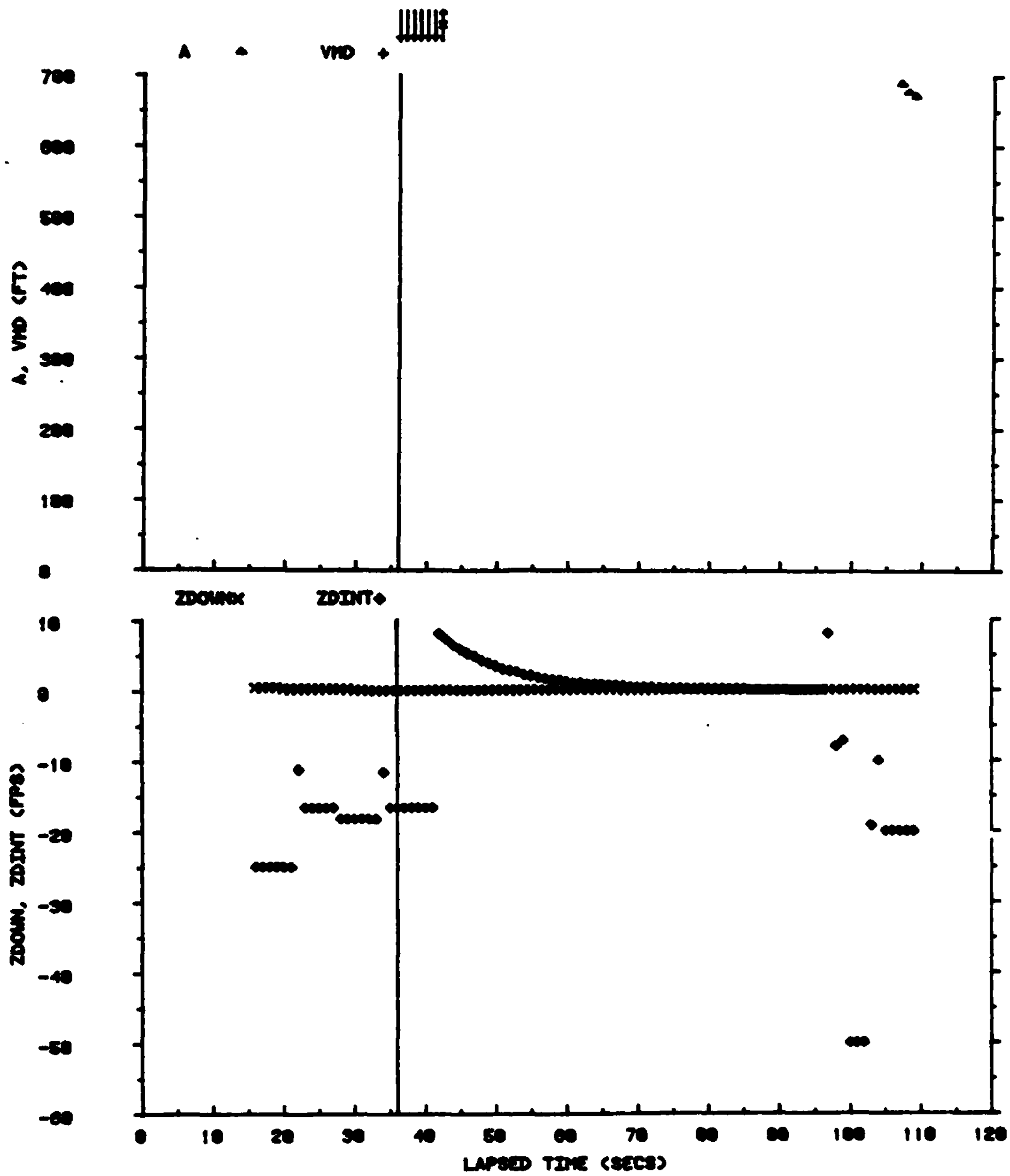
This case illustrates the ranges that advisories would be given for high speed encounters. The computed closure rate in this encounter is approximately 900 knots.



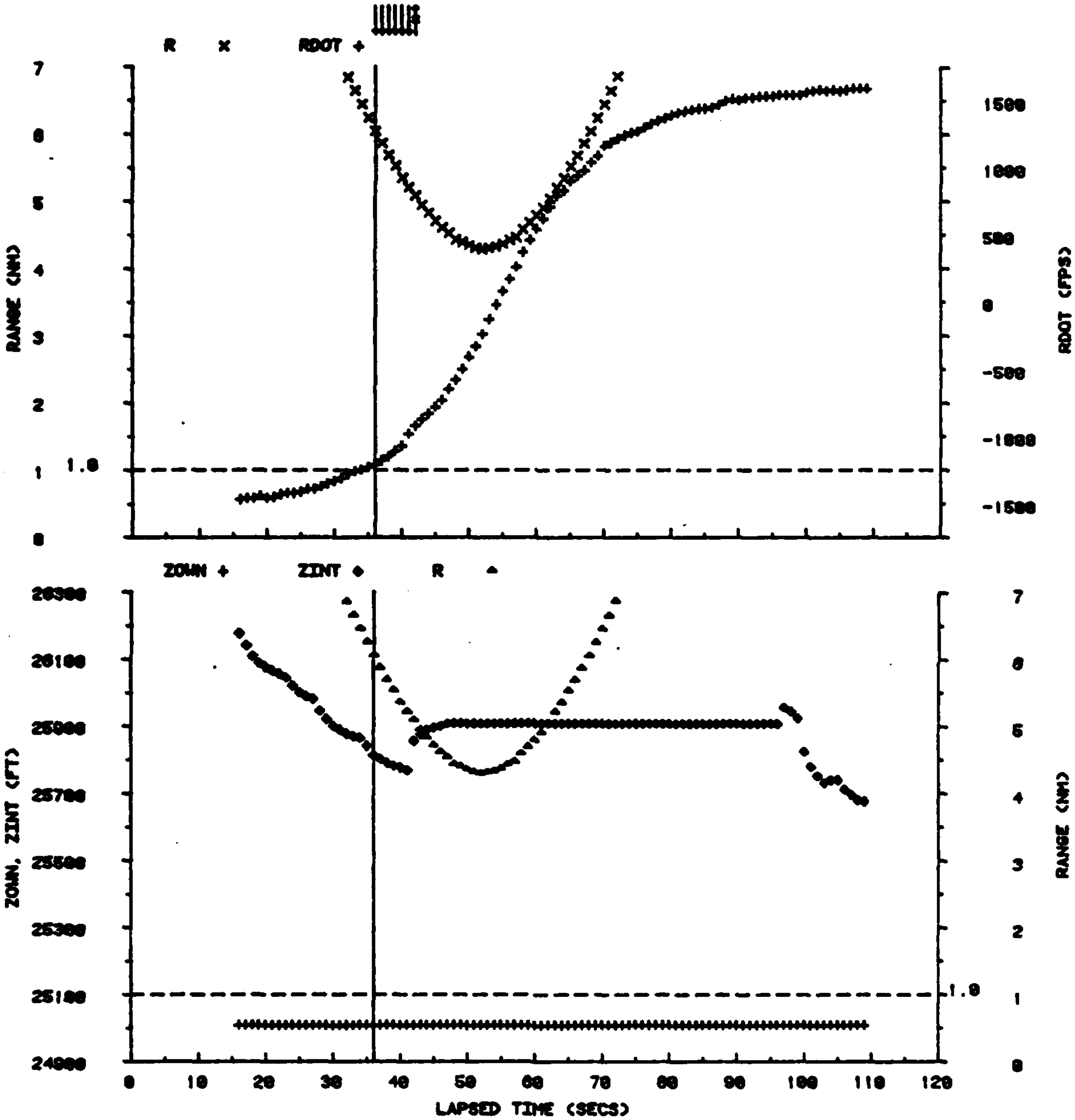
TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
LAPSED TIME (SECS)
30



7
5
3
1
1
3
5
7



A
VMD
A, VMD (FT)
700
600
500
400
300
200
100
0
ZDOWN×
ZDINT◆
ZDOWN, ZDINT (FPS)
10
0
-10
-20
-30
-40
-50
-60
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



R ×
RDOT +
RANGE (NM)
RDOT (FPS)
1.0
ZOWN +
ZINT ◆
R ▲
ZOWN, ZINT (FT)
RANGE (NM)
1.0
LAPSED TIME (SECS)

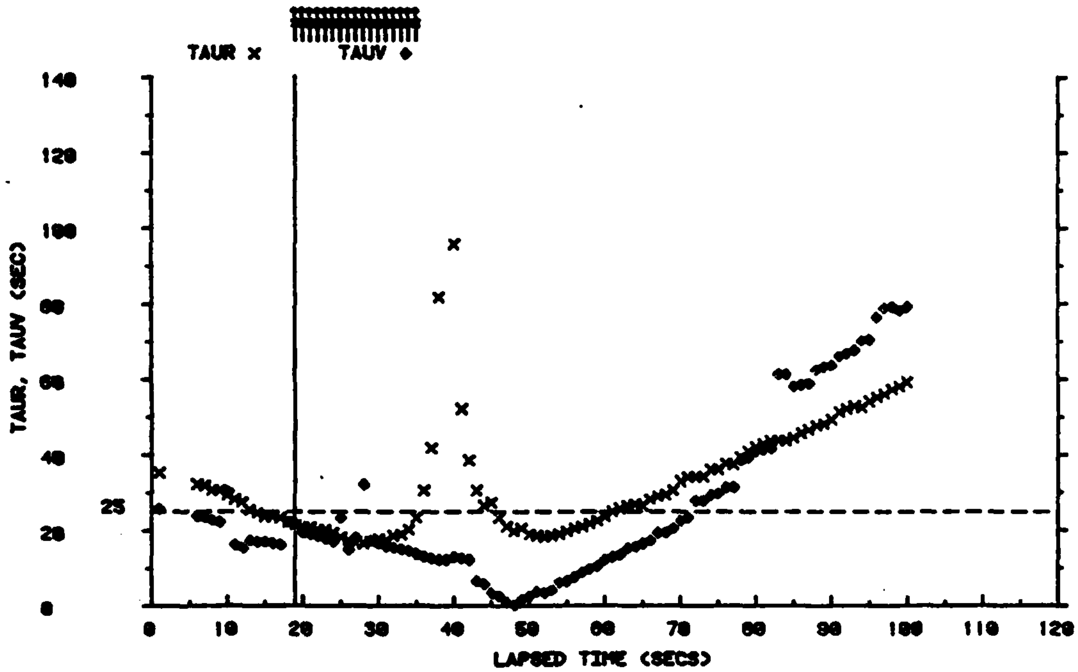
CASE 16

(Tape A033, Intruder 187) Don't Climb - Norfolk, Virginia Departure, February 20, 1982

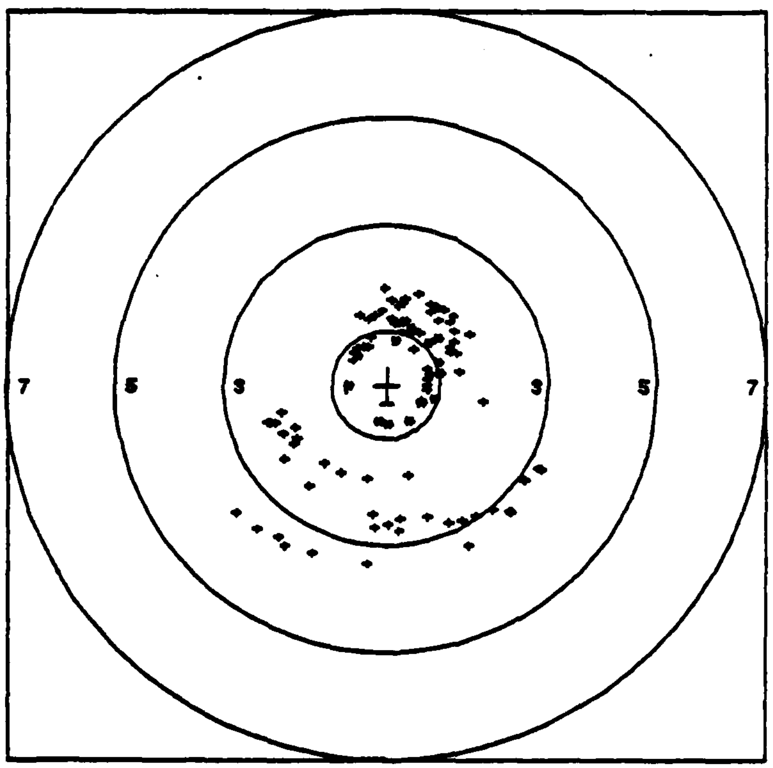
On the Afternoon of February 20, 1982, the test aircraft operated as Piedmont Flight 55 between Norfolk, Virginia and Charlotte, N.C. An ARINC Research and a FAA observer were aboard. Six minutes after departing Norfolk Regional Airport, Flight 55 was approximately 20 miles west of Norfolk, flying westbound at 8000 feet. ATC advised of southbound traffic at 12 o'clock, 3 miles, at 8500 feet. The pilot visually acquired a Cessna 172 almost simultaneously with the TCAS giving a traffic advisory on traffic at 1 o'clock, 3 miles and 500 feet above the test aircraft. The pilot of Flight 55 reported the visual acquisition of the Cessna to ATC and was cleared to continue his climb and maintaining visual separation on the Cessna. The TCAS gave a "DON'T CLIMB" resolution advisory, however the flight crew, who were unaware of the TCAS advisory, continued their climb.

The FAA observer felt the resolution was issued in sufficient time to comply and was the correct advisory.

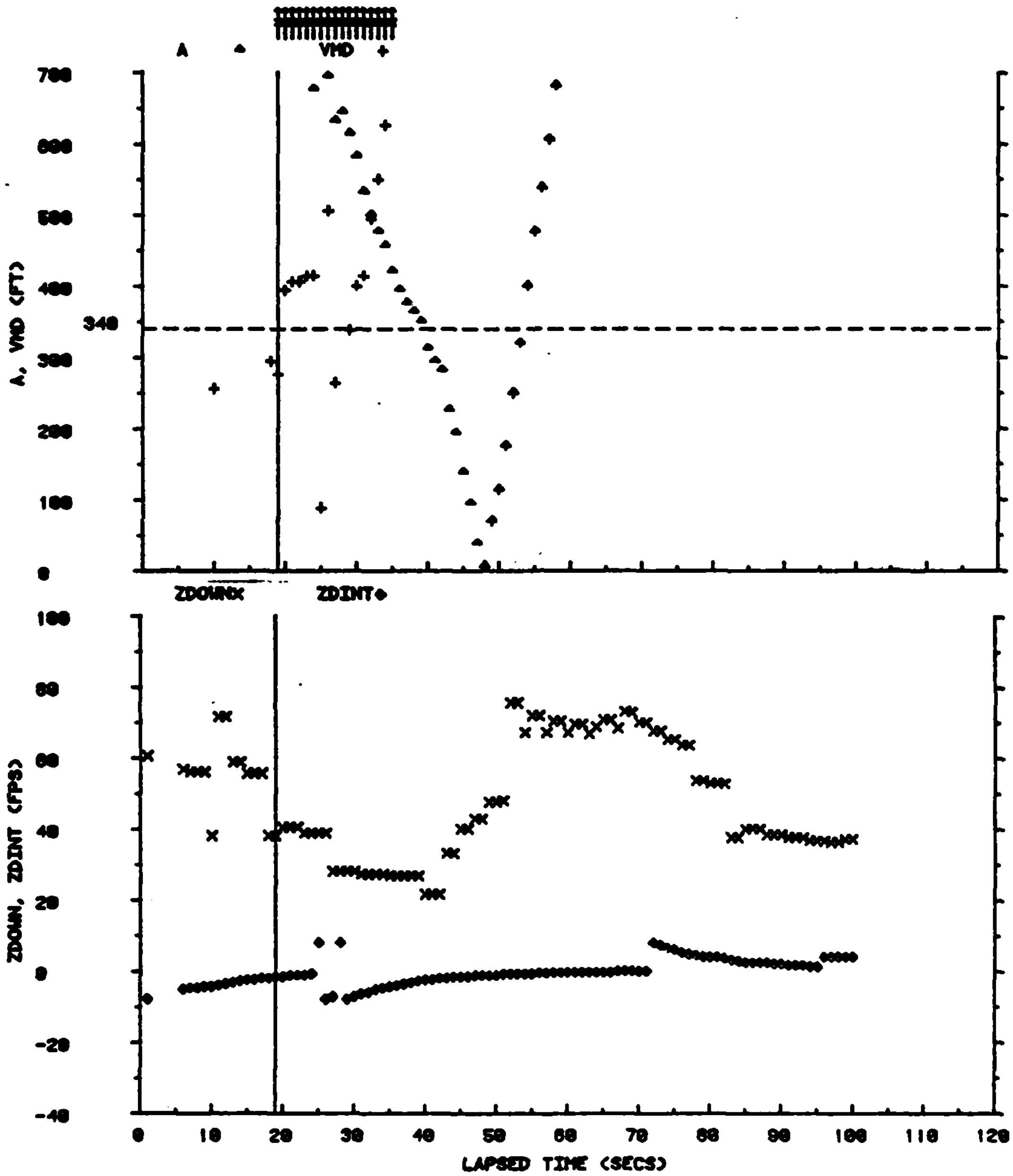
Subsequent examination of the recorded data confirmed the observer account of the incident. This tape also revealed a failure in one of the receivers that caused the bearing data to be unreliable, as shown in the bearing plot.



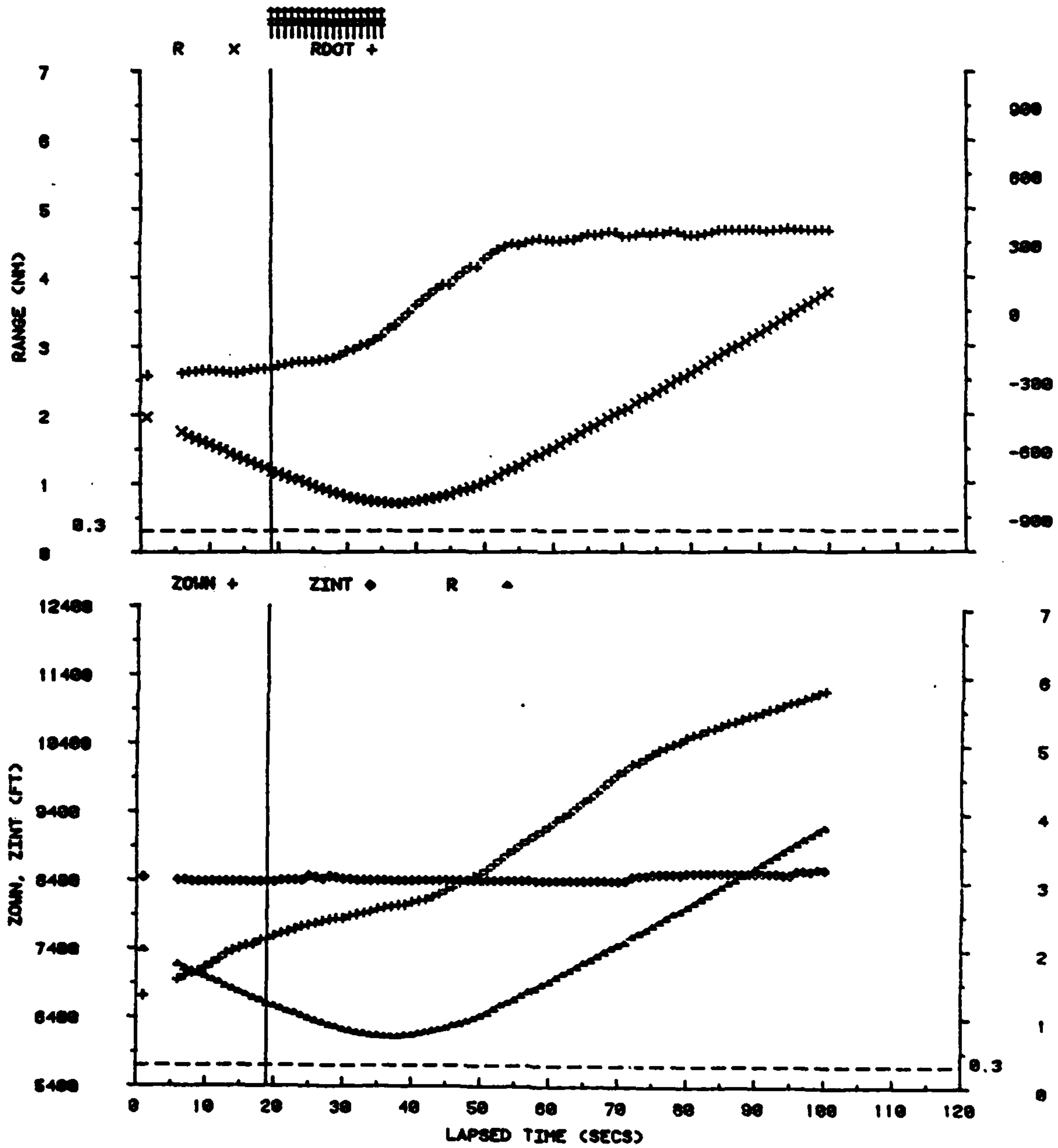
TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
0
20
25
40
60
80
100
120
140
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
3
5
7



A
VMD
+
700
600
500
400
340
300
200
100
0
A, VMD (FT)
ZDOWN×
ZDINT◆
100
80
60
40
20
0
-20
-40
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

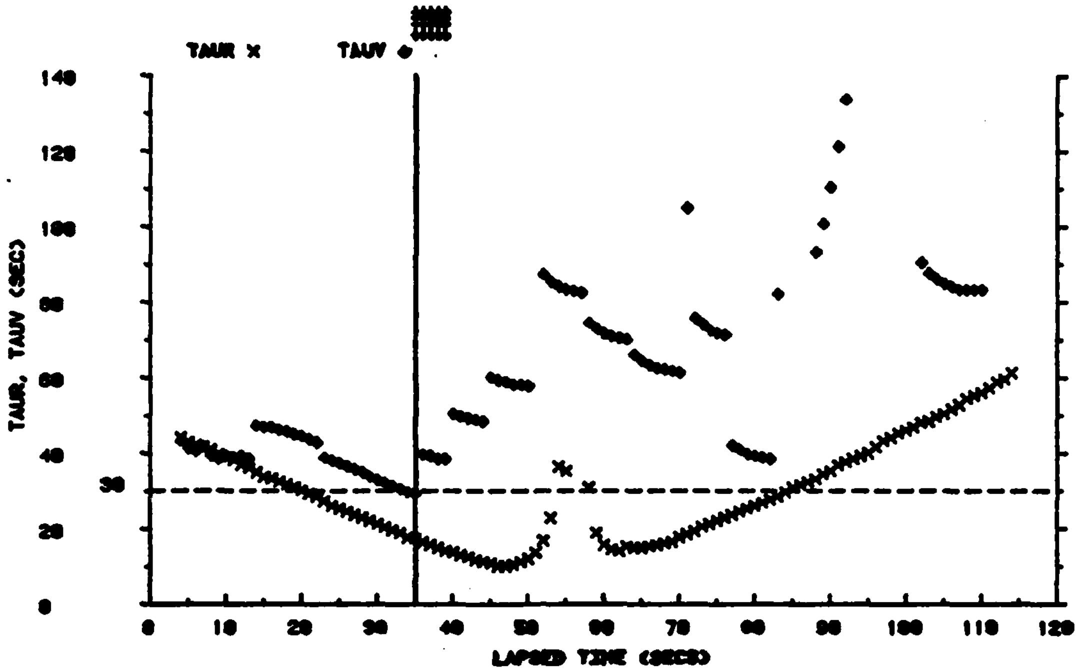


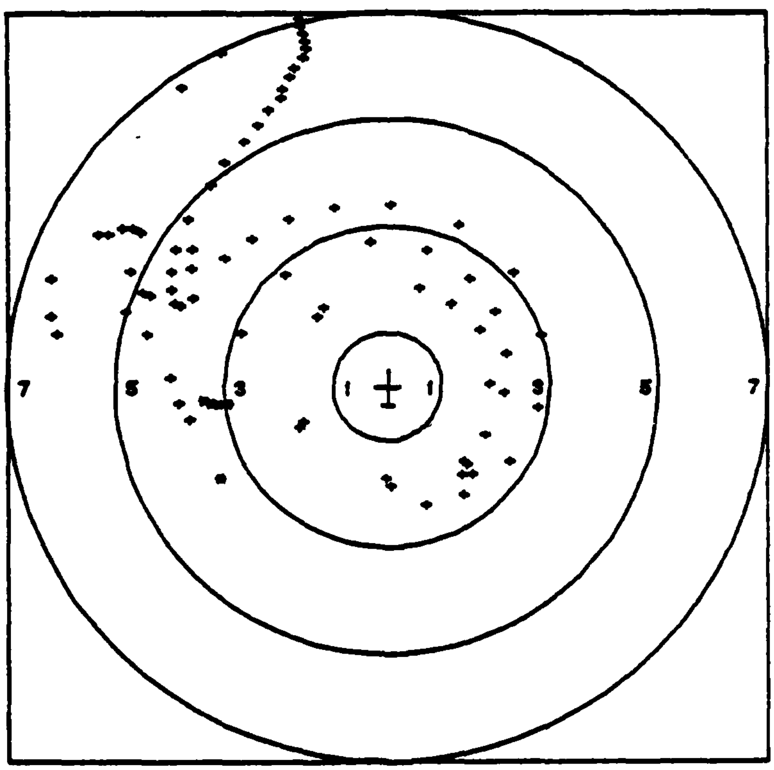
R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZOWN +
ZINT ◆
R ▲
ZOWN, ZINT (FT)
RANGE (NM)
0.3
LAPSED TIME (SECS)

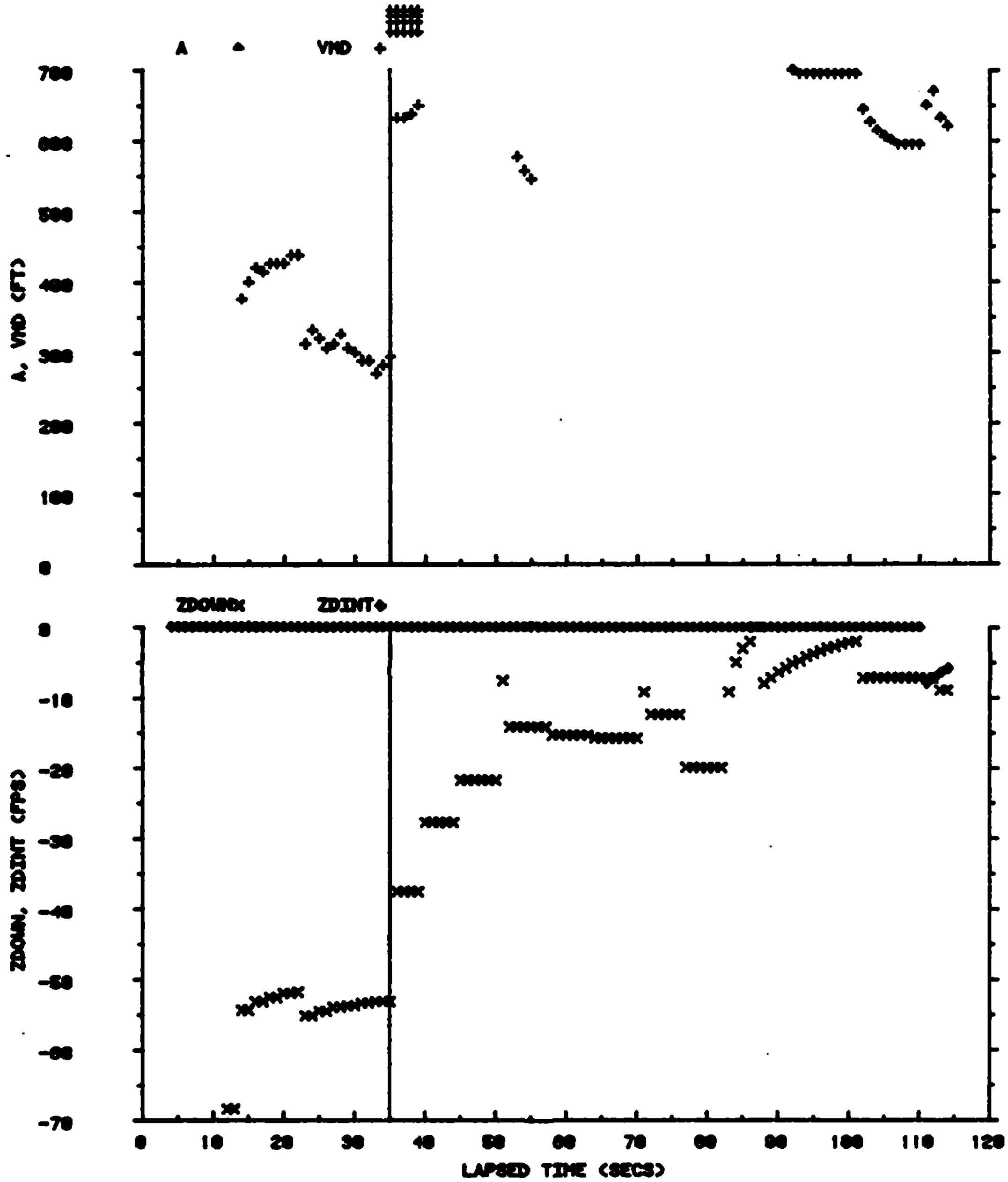
CASE 17

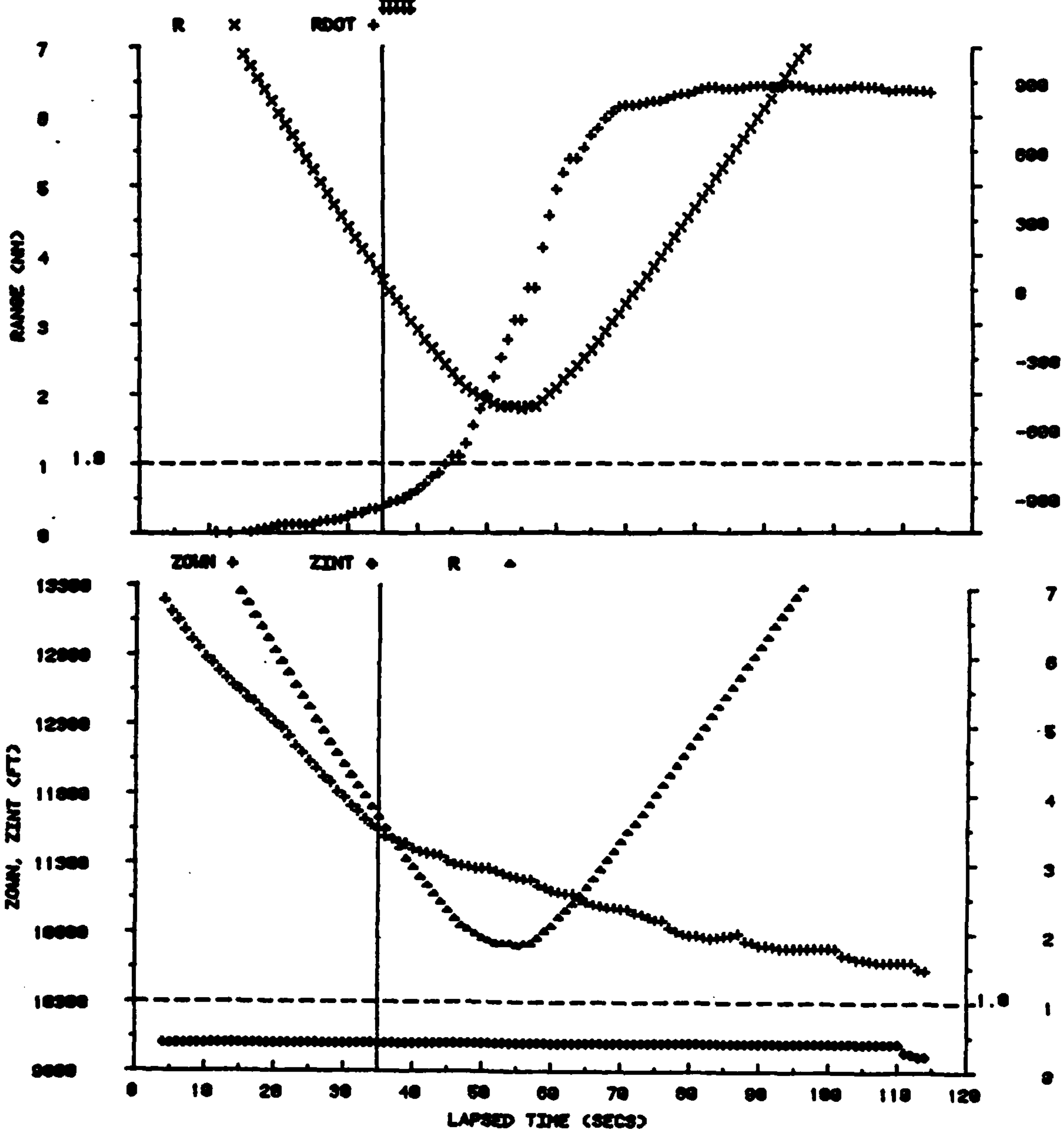
(Tape A038, Intruder 5) Limit Descent During Descent Phase of Flight

The recorded data on this unobserved encounter shows the test aircraft in a descent from above 13,000 feet, with the intruder level at 10,000 feet. The two aircraft cross at a range of 1.6 miles with 1500 feet vertical separation. The LIMIT DESCENT TO 1500 FPM advisory is given at a range of 3.5 miles for this encounter where the closing rate is greater than 500 knots.


TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
LAPSED TIME (SECS)
30


7
5
3
1
1
3
5
7


A
VND
700
600
500
400
300
200
100
0
A, VND (FT)
ZDOWN
ZDINT
0
-10
-20
-30
-40
-50
-60
-70
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



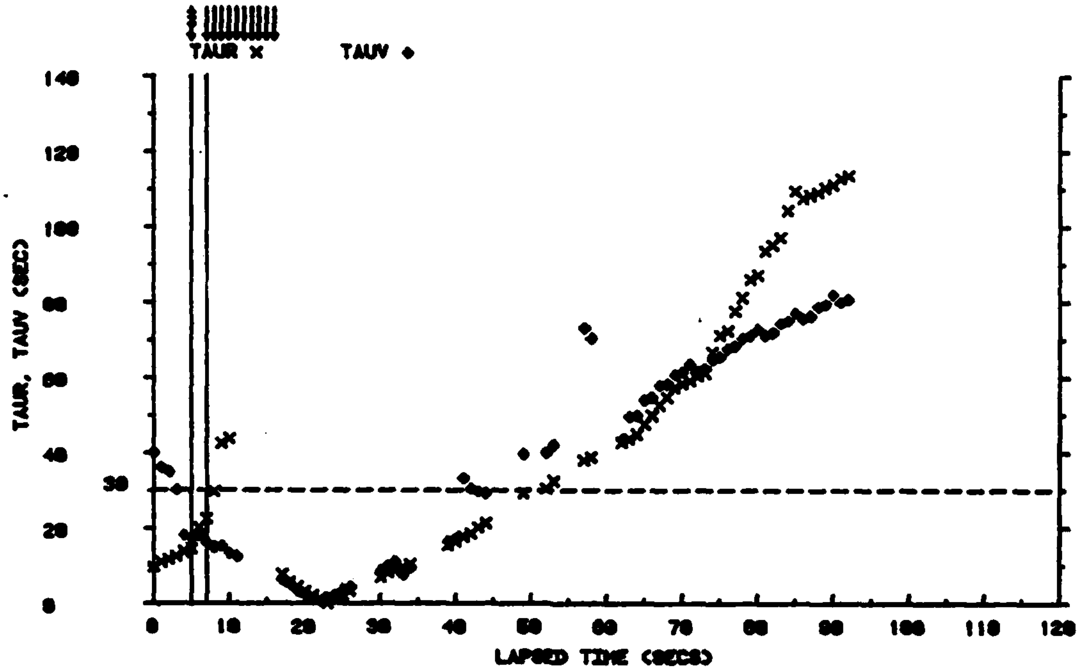
R ×
RDOT +
7
6
5
4
3
2
1
0
RANGE (NM)
1.0
900
600
300
0
-300
-600
-900
RDOT (FPS)
ZOWN +
ZINT ◆
R ▲
13300
12800
12300
11800
11300
10800
10300
9800
ZOWN, ZINT (FT)
RANGE (NM)
1.0
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

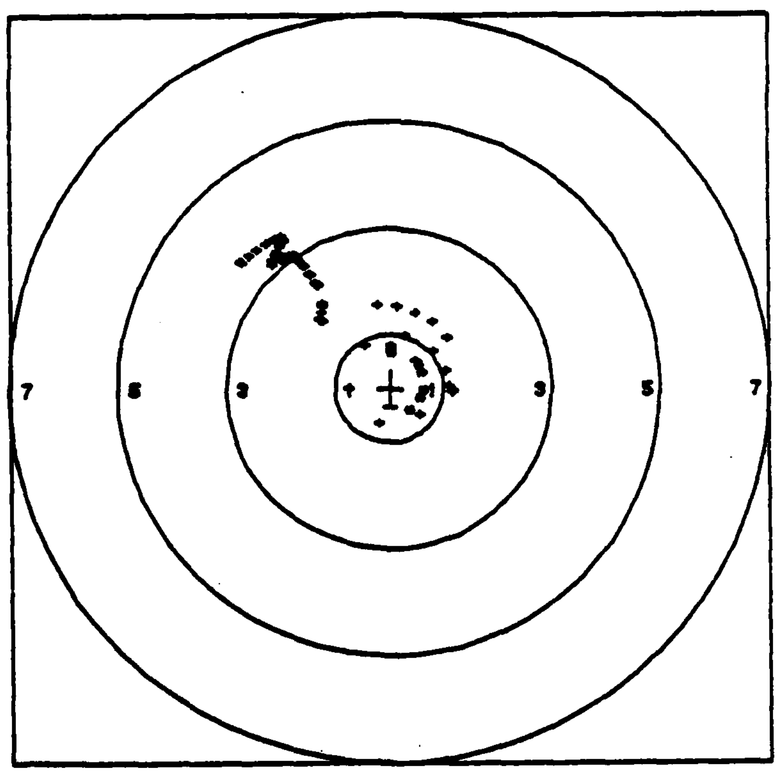
CASE 18

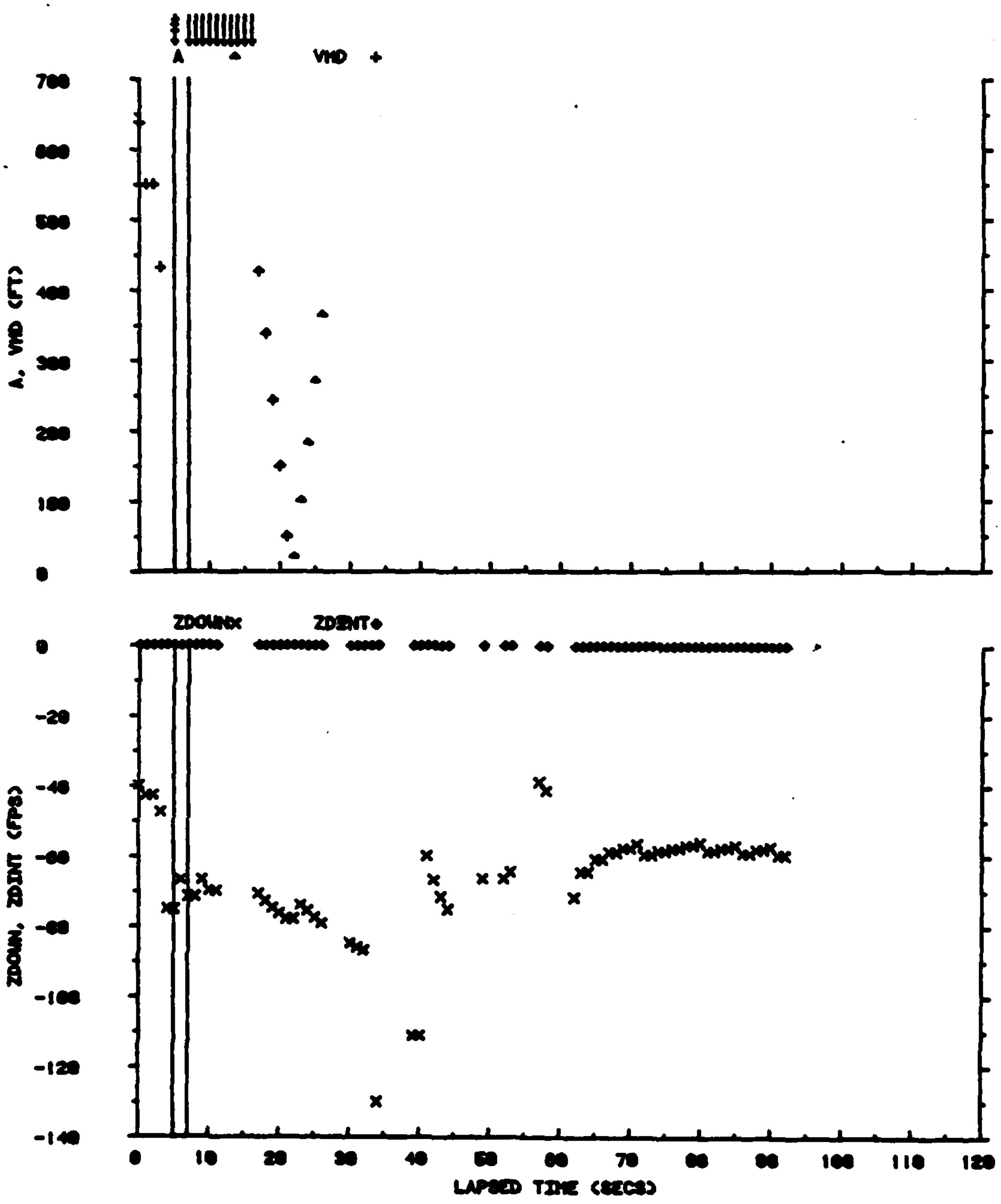
(Tape A046, Intruder 172/168) Unobserved Limit Descent (2,000 FPM)/ Descend Advisories on Level Intruder during Descent

During this encounter own aircraft is descending out of an en route altitude in excess of 12,000 feet. The intruder remains level at 10,600 feet. Angle of arrival and range rate information suggest that a turn was involved in resolving this conflict situation. The encounter took place while the test aircraft was transitioning from en route to approach phase of flight.

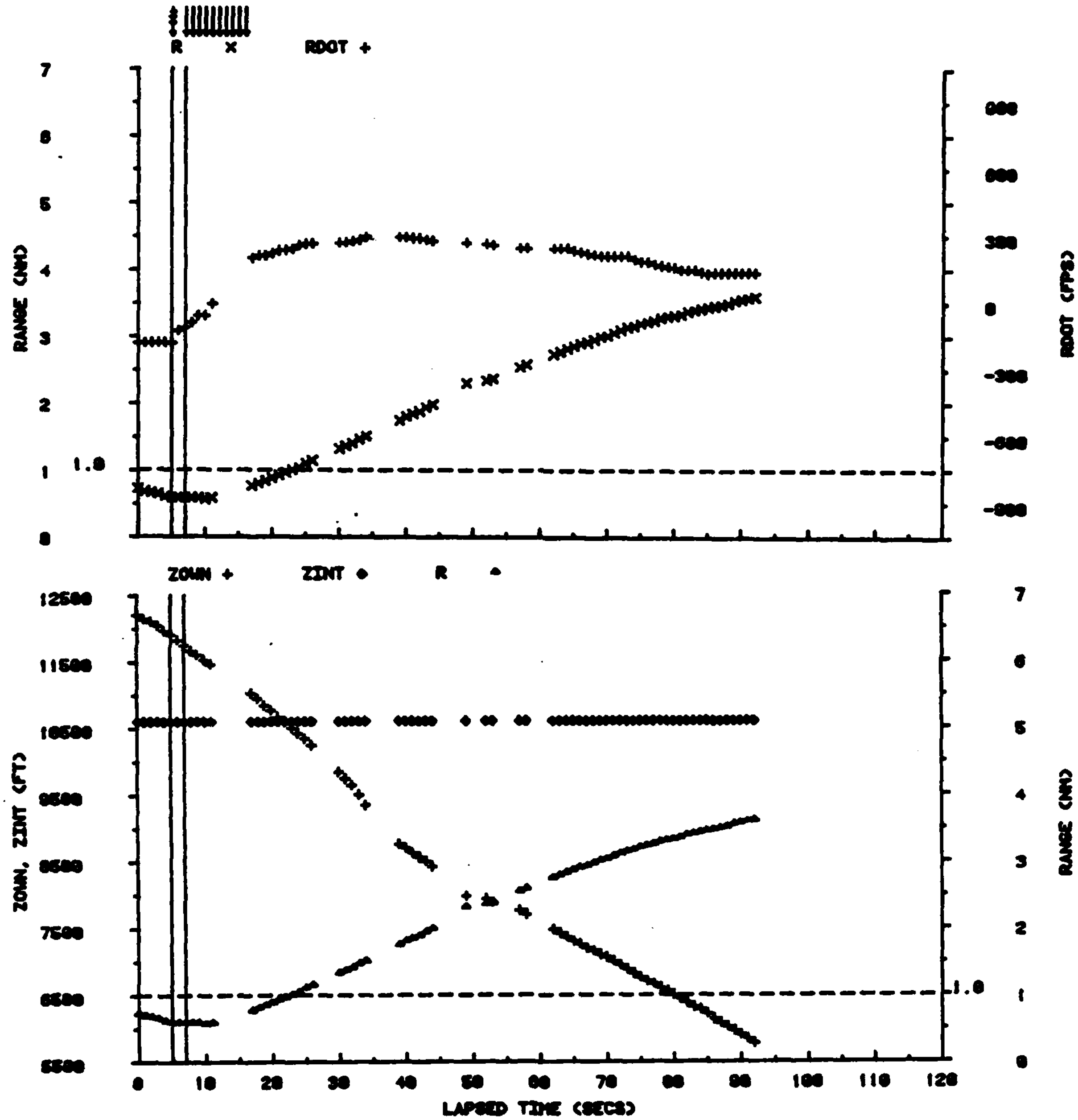
At the time the two aircraft were at the minimum range of 0.5 miles, they were separated vertically by 1000 feet.


TAUR ×
TAUV ◆
140
120
100
80
60
40
30
20
0
0
10
20
30
40
50
60
70
80
90
100
110
120
TAUR, TAUV (SEC)
LAPSED TIME (SECS)


7
5
3
3
5
7



A
VHD +
A, VHD (FT)
ZDOWN×
ZDINT◆
ZDOWN, ZDINT (FPS)
LAPSED TIME (SECS)

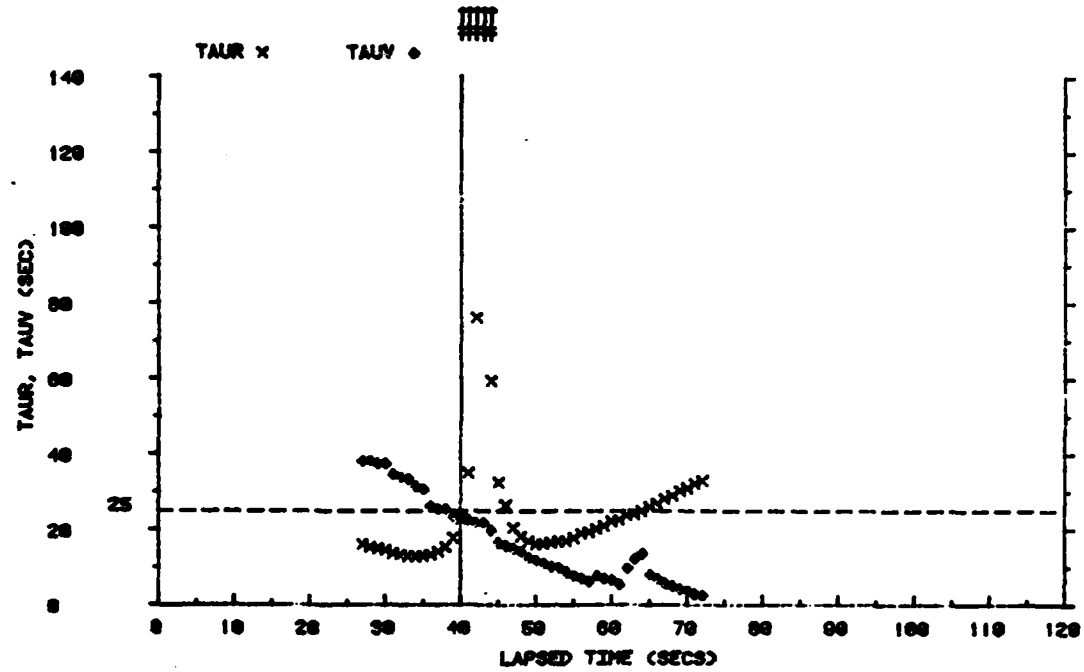


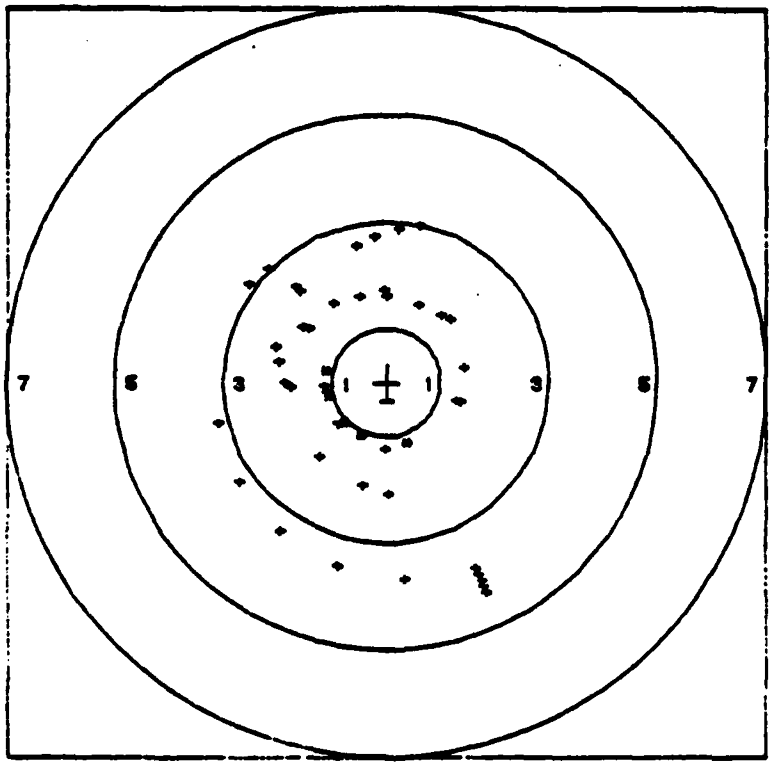
R
X
RDOT +
RANGE (NM)
RDOT (FPS)
1.0
ZOWN +
ZINT ◆
R
LAPSED TIME (SECS)
ZOWN, ZINT (FT)
RANGE (NM)

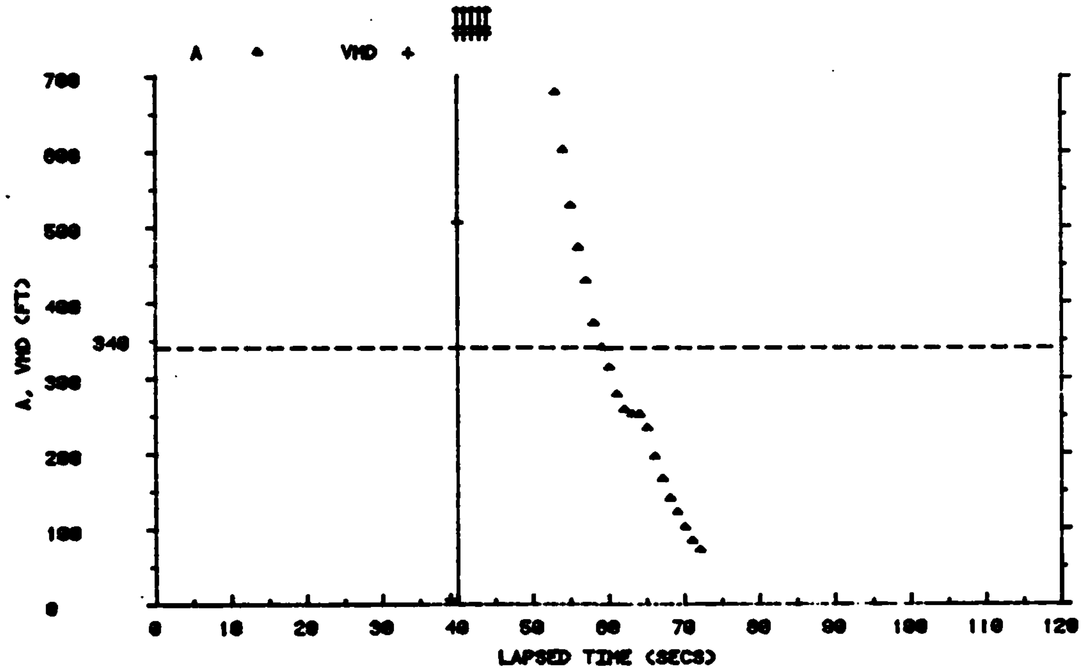
CASE 19

(Tape A049, Intruder 183) Unobserved Limit Climb (1,000 FPM)

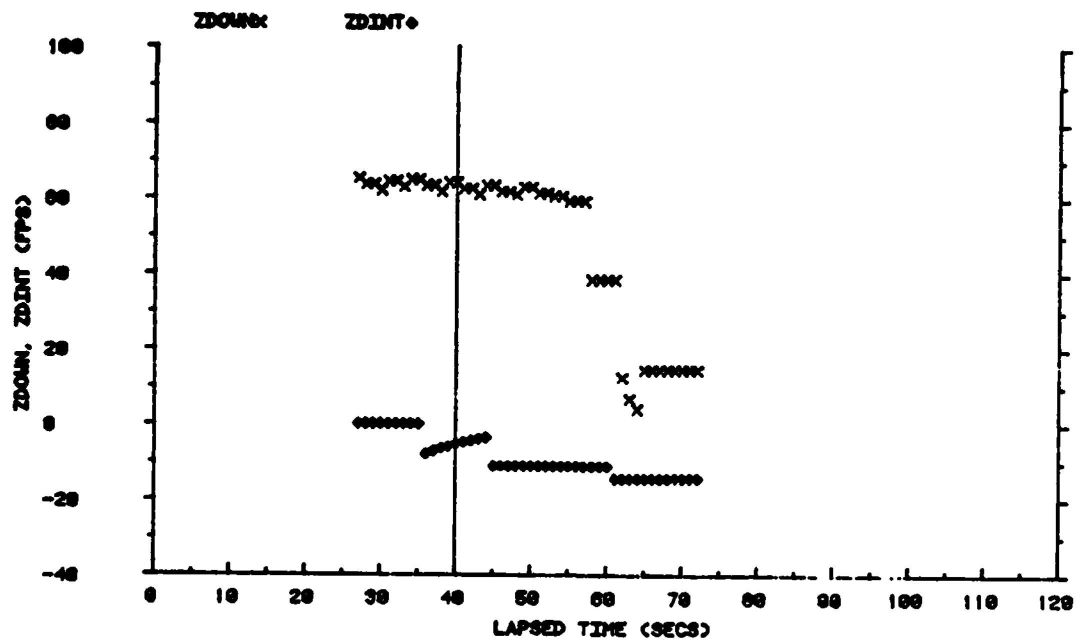
During this encounter own aircraft makes departure climb to approximately 9,000 feet as the intruder is the process of making a very gentle descent. The intruder is incrementally tracked as near level flight. At the time the two aircraft are at the minimum range of 1 mile, they have 1500 feet of vertical separation.


TAUR ×
TAUV ◆
140
120
100
80
60
40
25
20
0
TAUR, TAUV (SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

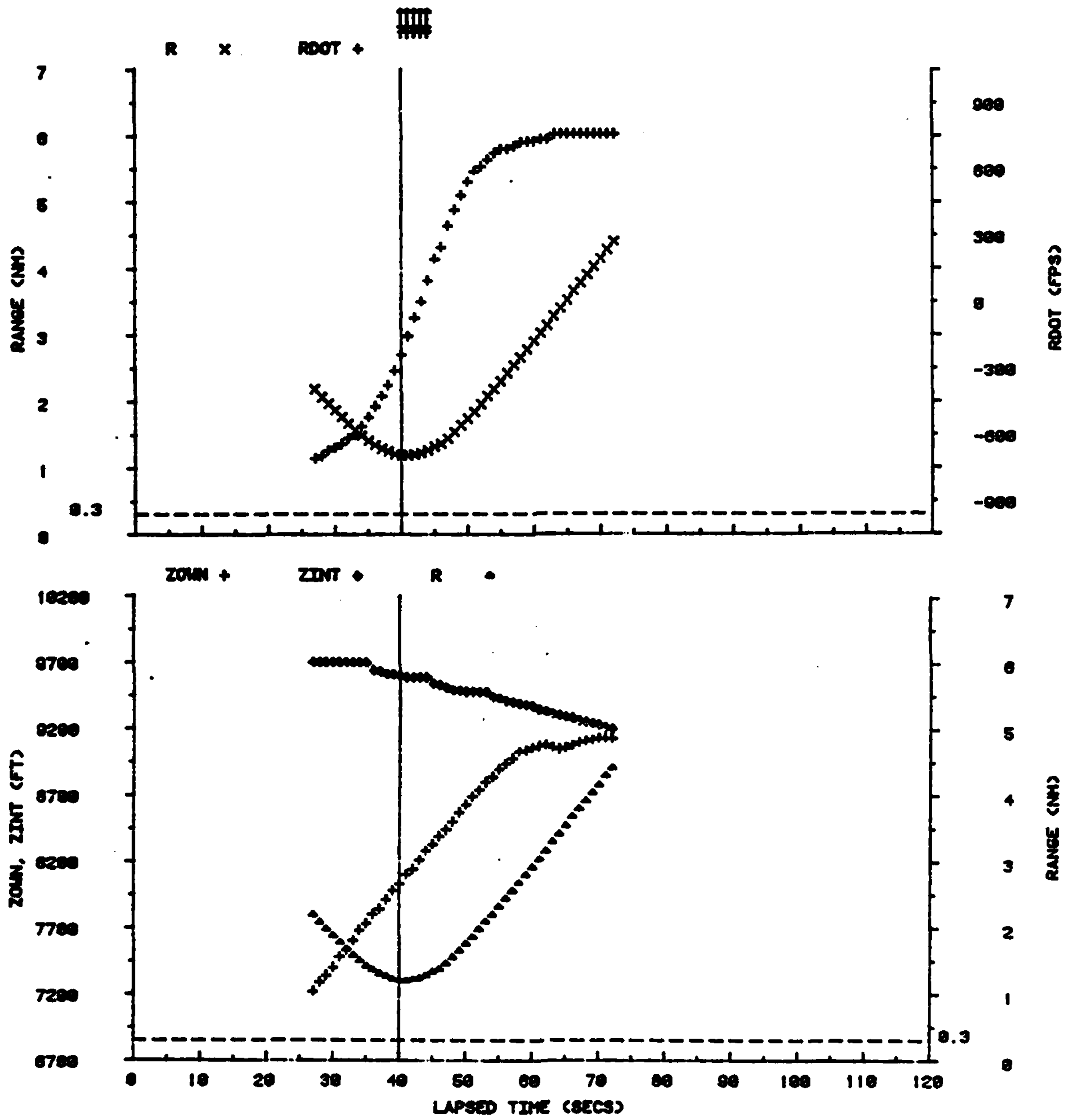

7
5
3
1
1
3
5
7



A
VHD
700
600
500
400
340
300
200
100
0
A, VHD (FT)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



ZDOWN
ZDINT
100
80
60
40
20
0
-20
-40
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

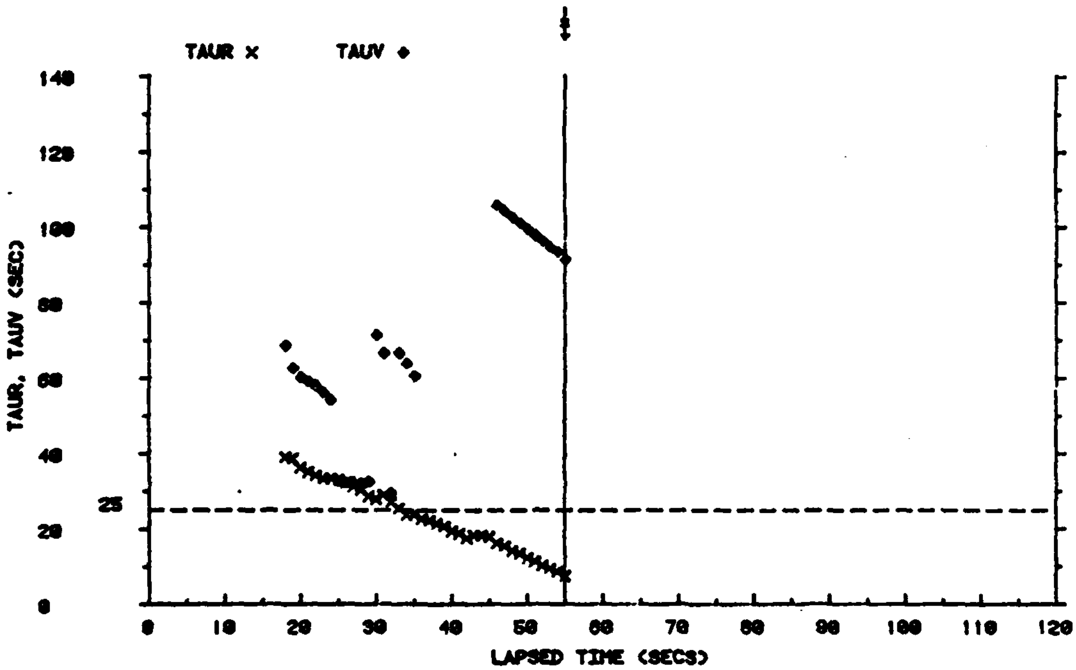


R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZOWN +
ZINT ◆
R ◆
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

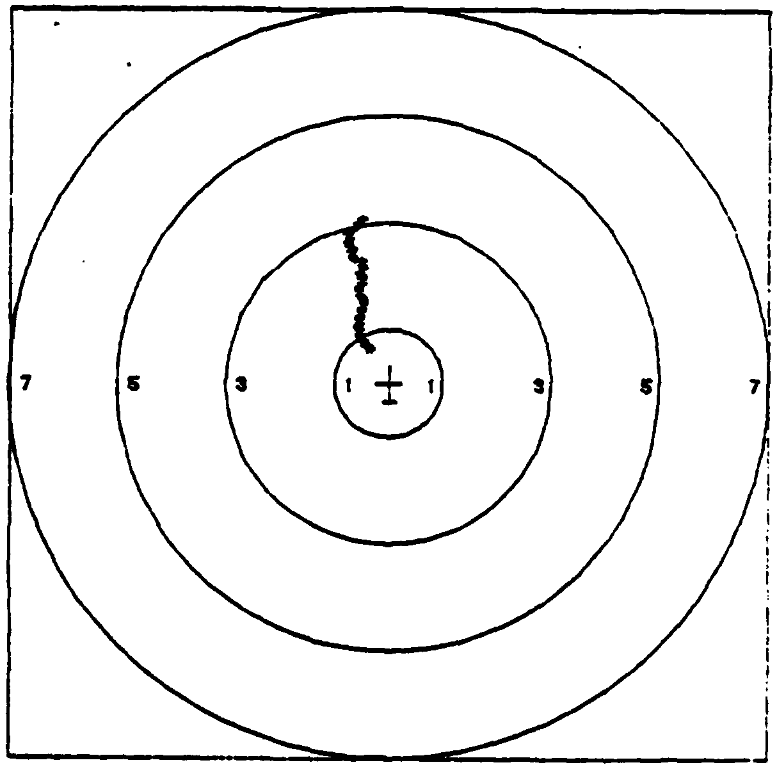
CASE 20

(Tape A052, Intruder 175) Unobserved Don't Descend

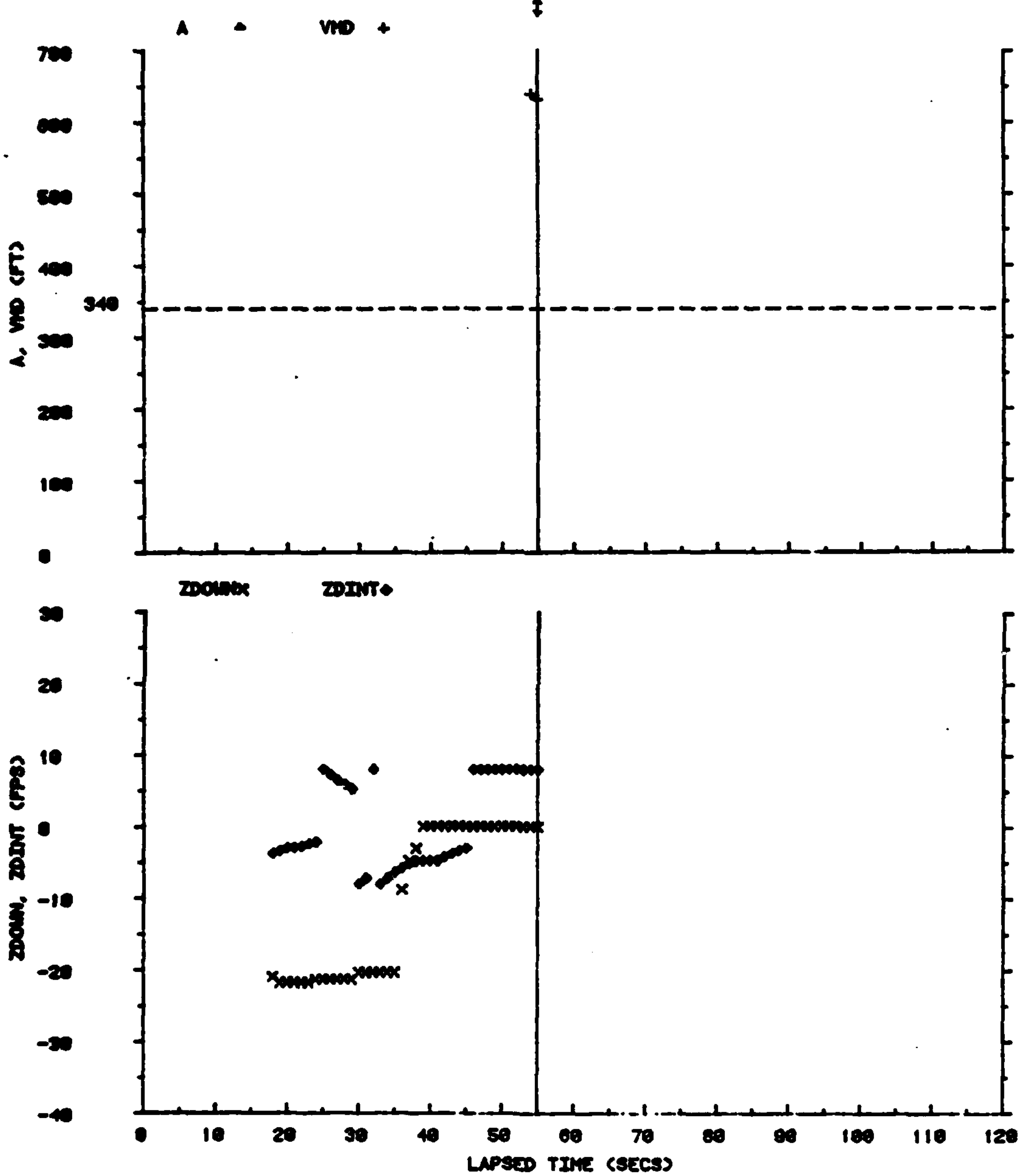
In this encounter a traffic advisory was generated on an intruder at 3 miles, almost directly ahead of the test aircraft. The test aircraft descended and leveled off 1000 feet above the intruder. The intruder started a climb immediately thereafter. When the two aircraft were at the minimum range of 0.6 miles they were separated 700 feet in altitude. A one-second DON'T DESCEND advisory was given at this point and the track was dropped by the system. This type of track drop anomoly is under study by the technical development team.



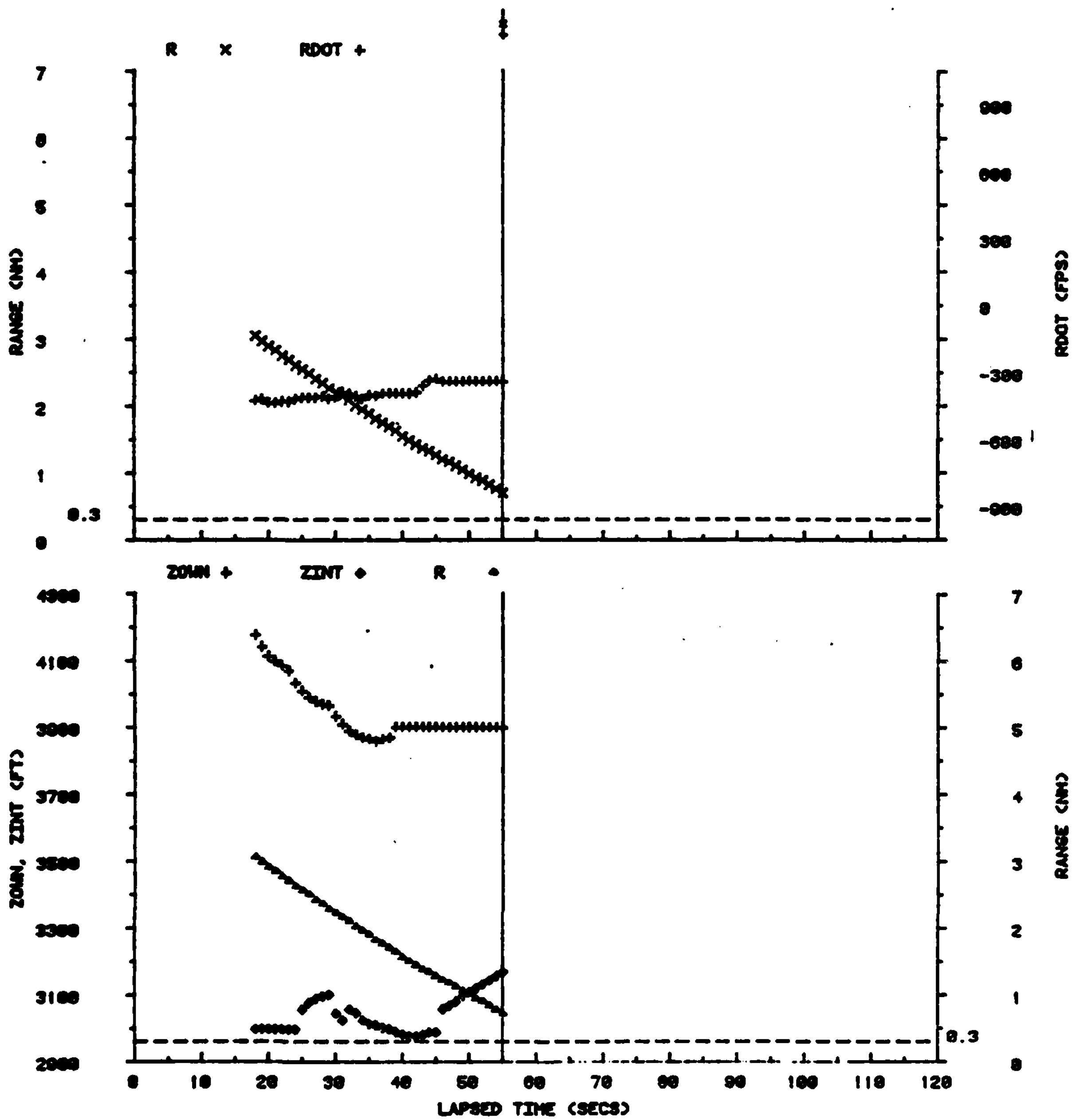
TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
LAPSED TIME (SECS)
25



7 5 3 1 1 3 5 7



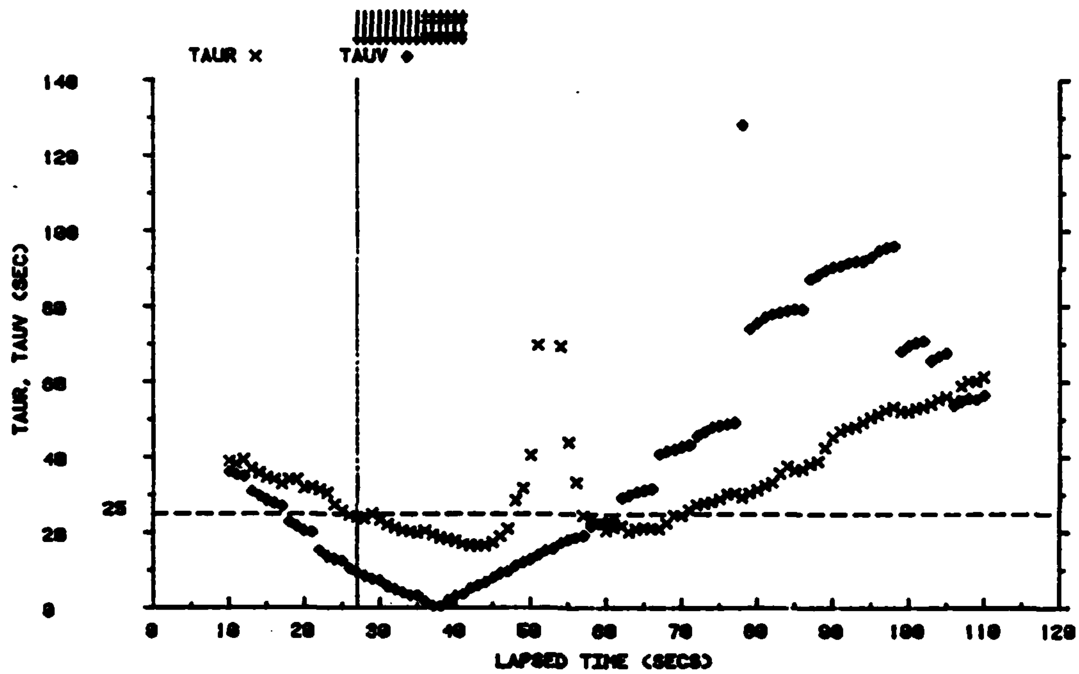
A
VMD +
700
600
500
400
340
300
200
100
0
A, VMD (FT)
ZDOWN×
ZDINT◆
30
20
10
0
-10
-20
-30
-40
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

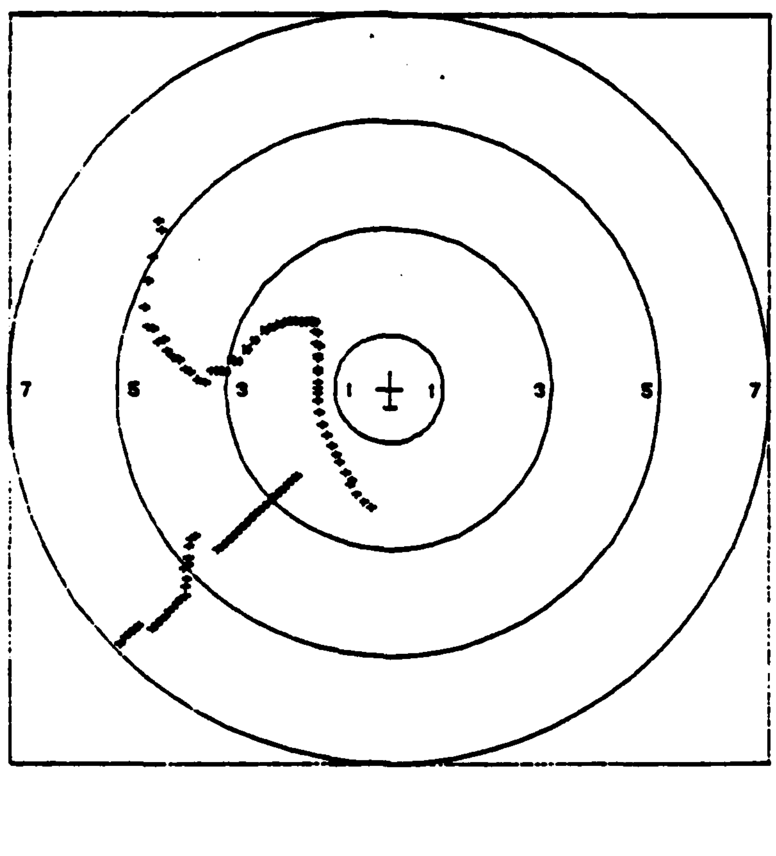

R × RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZDWN + ZINT ◆ R ◆
ZDWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

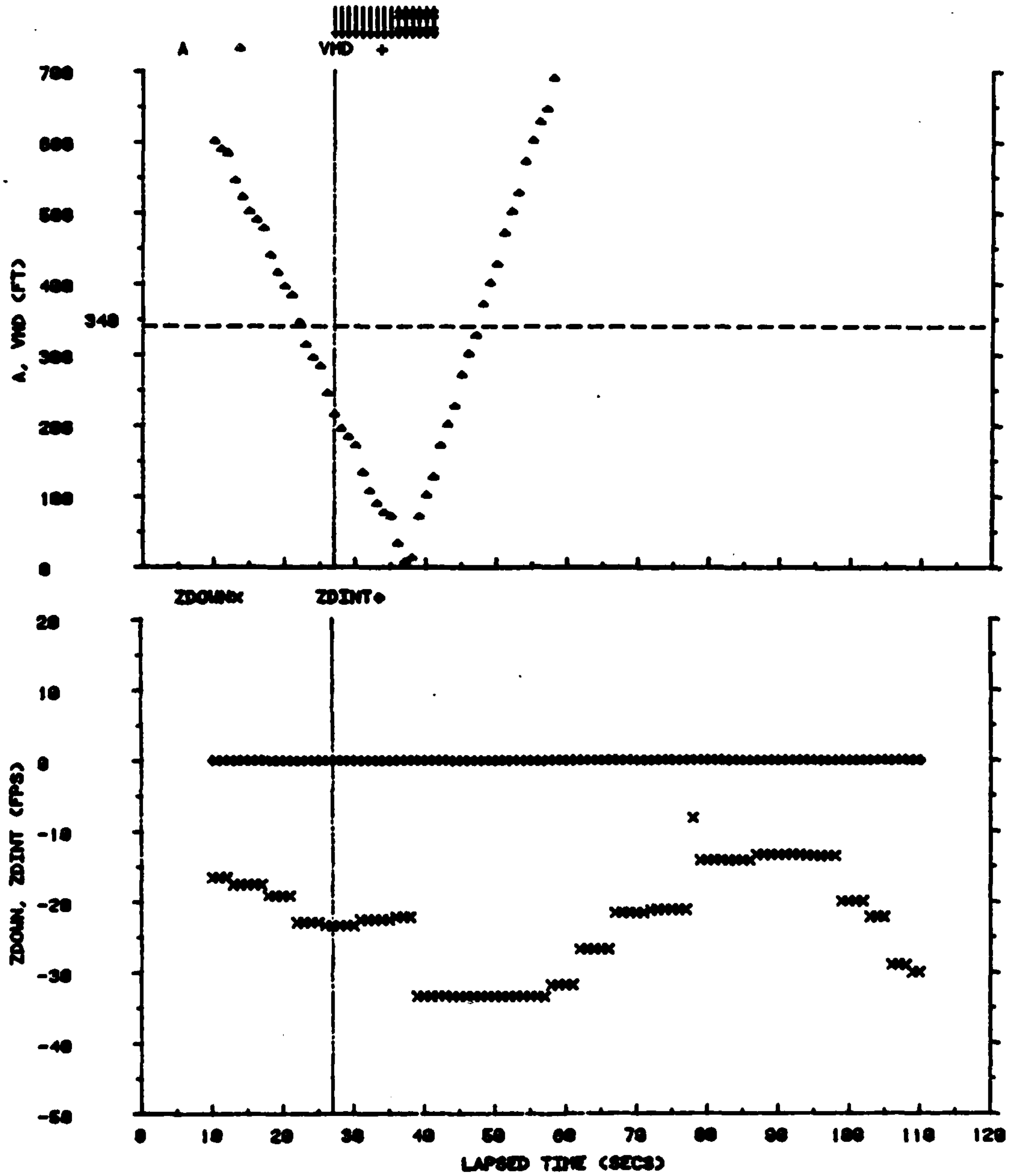
CASE 21

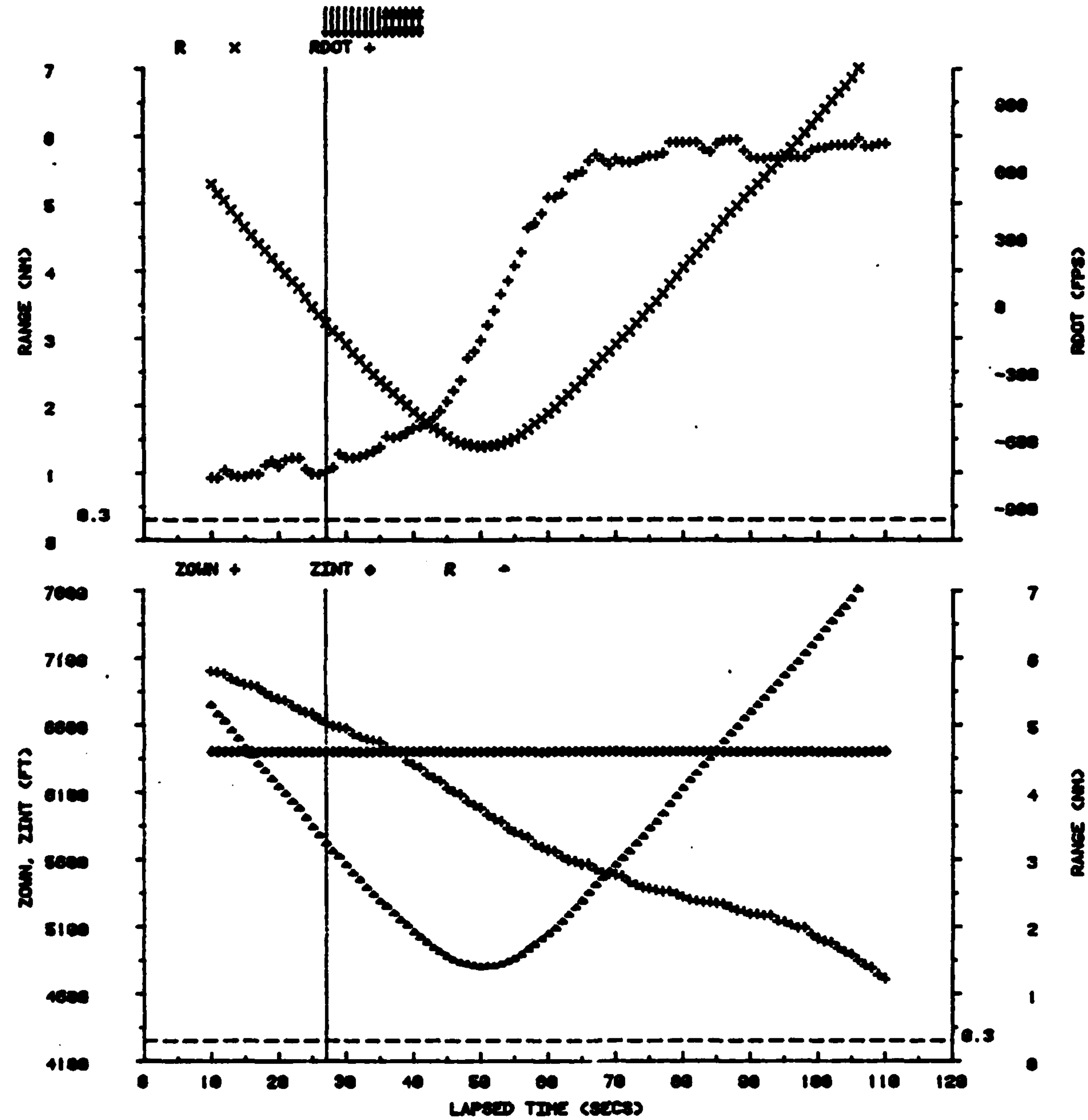
(Tape A054, Intruder 57) Positive Descend/Minimum Descent Advisories on Lower Level Intruder During Approach

This encounter, in which the intruder maintained a level altitude of 600 feet while the test aircraft descended through that altitude, appears to be a normal type of terminal area encounter. The bearing data shows that one or both aircraft were turning through the major portion of the encounter. At the time of the resolution advisory, range was 3 miles and altitude separation was 250 feet. The bearing plot and range rate plots indicate that the intruder made a left turn followed by a right turn of test aircraft shortly after the two aircraft crossed in altitude at a range of 2 miles. The aircraft continued to separate vertically thereafter, however minimum range closed to 1 mile before starting to separate.


TAUR ×
TAUV ◆
140
120
100
80
60
40
25
20
0
TAUR, TAUV (SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)


7
5
3
1
1
3
5
7


A
VMD
700
600
500
400
340
300
200
100
0
A, VMD (FT)
ZDOWN
ZDINT
20
10
0
-10
-20
-30
-40
-50
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

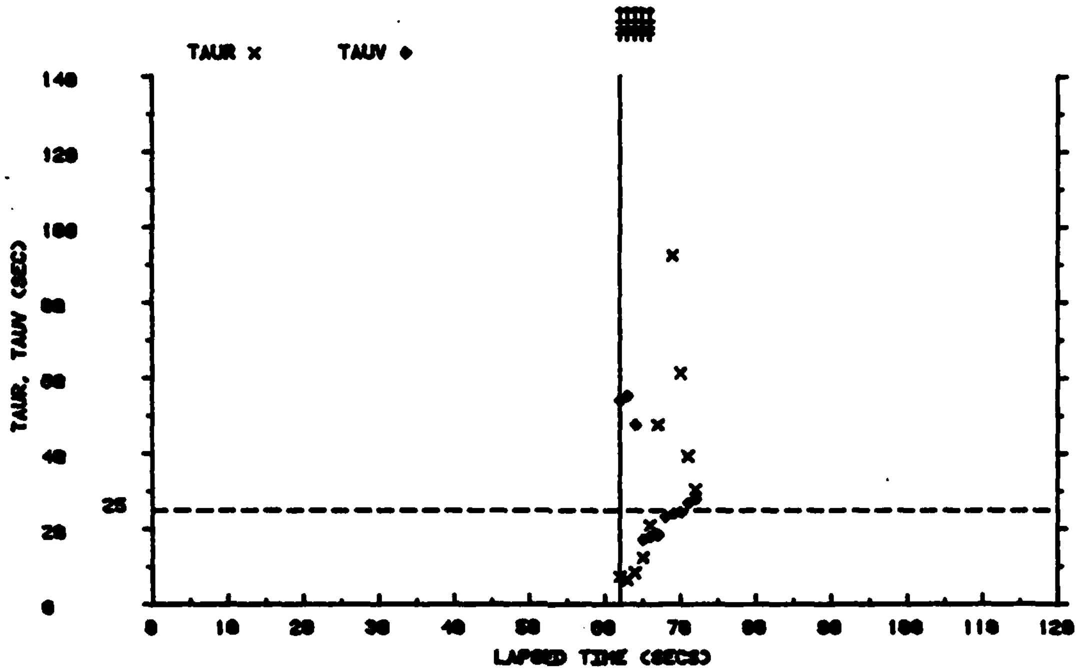

R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZOWN +
ZINT ◆
R ◆
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

CASE 22

(Tape B057, Intruder 190) Limit Climb (2,000 FPM) on Climbing Intruder Above Level Own Aircraft at Ground Level

During this incident own aircraft is believed to have been on take-off at Denver. This aircraft was equipped with a nose gear weight sensor and appears to have sensed itself airborne before the aircraft actually left the ground. Own aircraft appears to be on the ground with an advisory having been given on a departing aircraft, probably from a parallel runway.

At the start of this advisory range, vertical TAU, altitude separation, and projected vertical miss distance were below thresholds for threat declaration. Altitude separation and projected vertical miss distance were outside the limit for positive advisories and a negative Limit Climb (2,000 FPM) advisory was selected.


TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
140
120
100
80
60
40
25
20
0
0
10
20
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40
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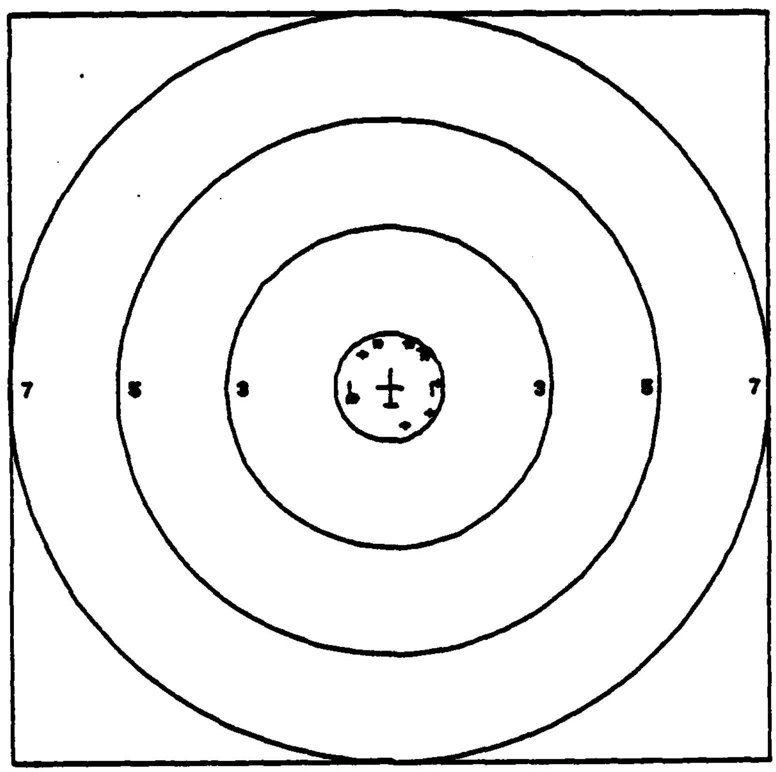
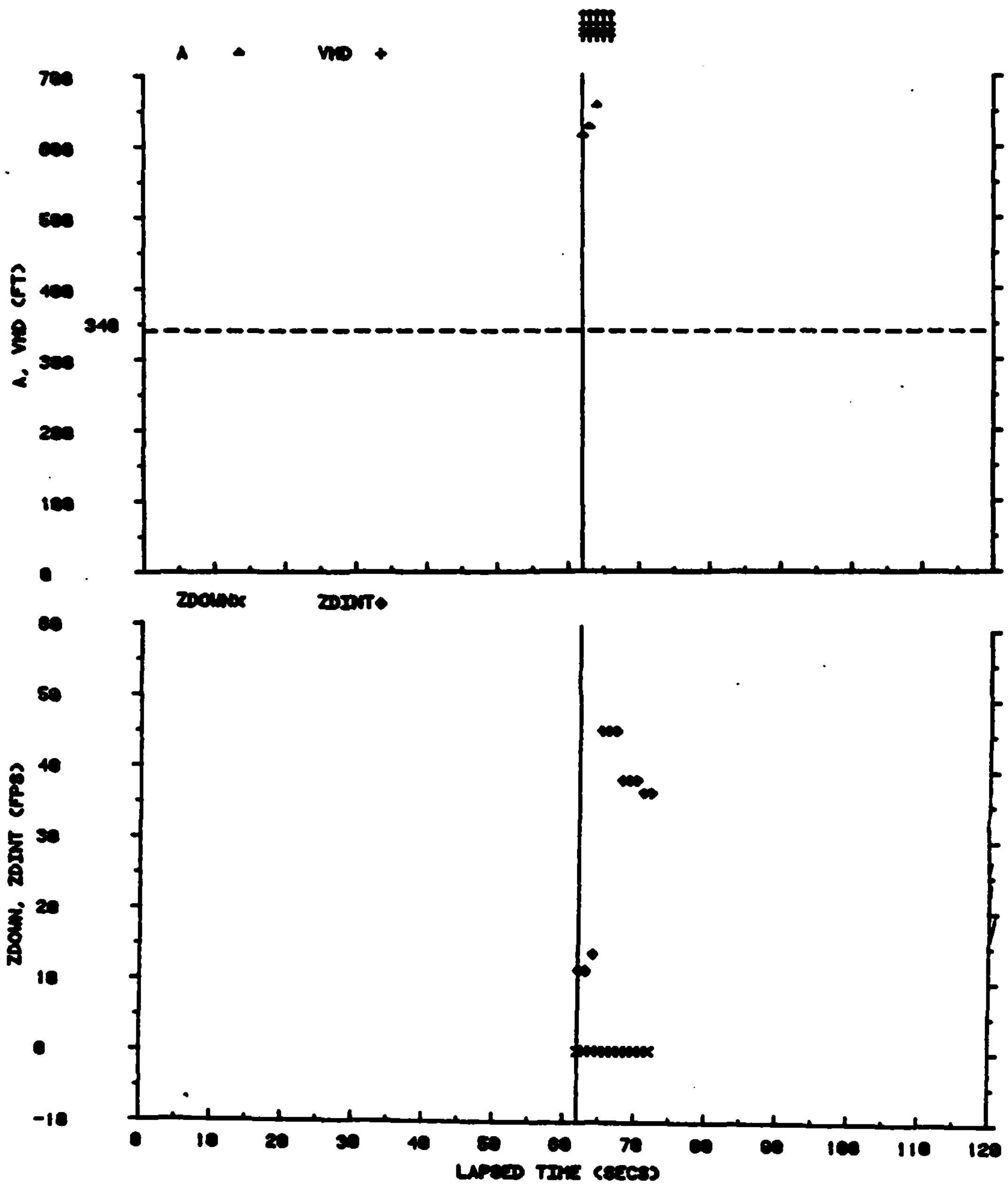
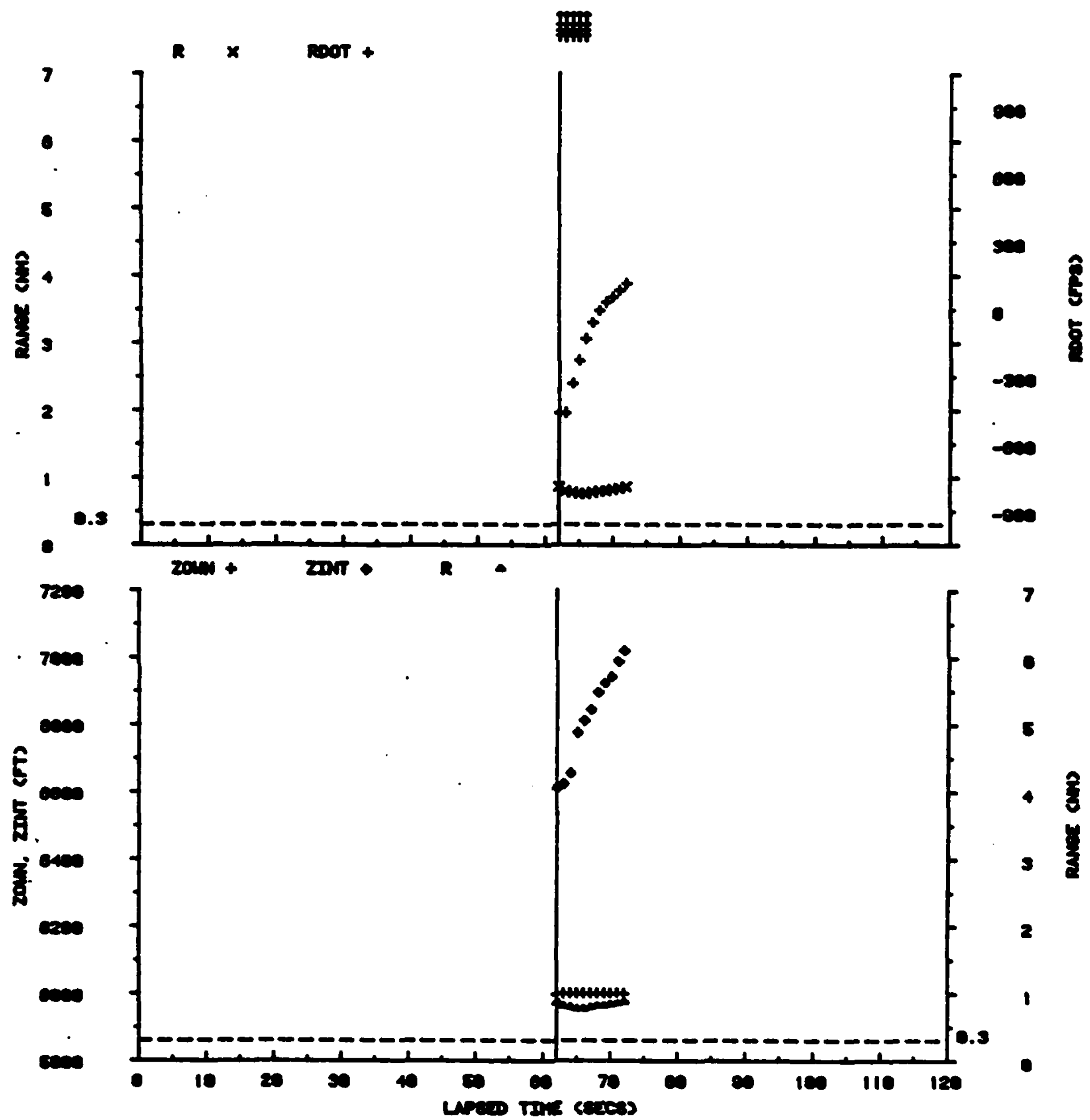
100
110
120
LAPSED TIME (SECS)


7
5
3
3
5
7



A
VHD
700
600
500
400
340
300
200
100
0
A, VHD (FT)
ZDOWN×
ZDINT◆
60
50
40
30
20
10
0
-10
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

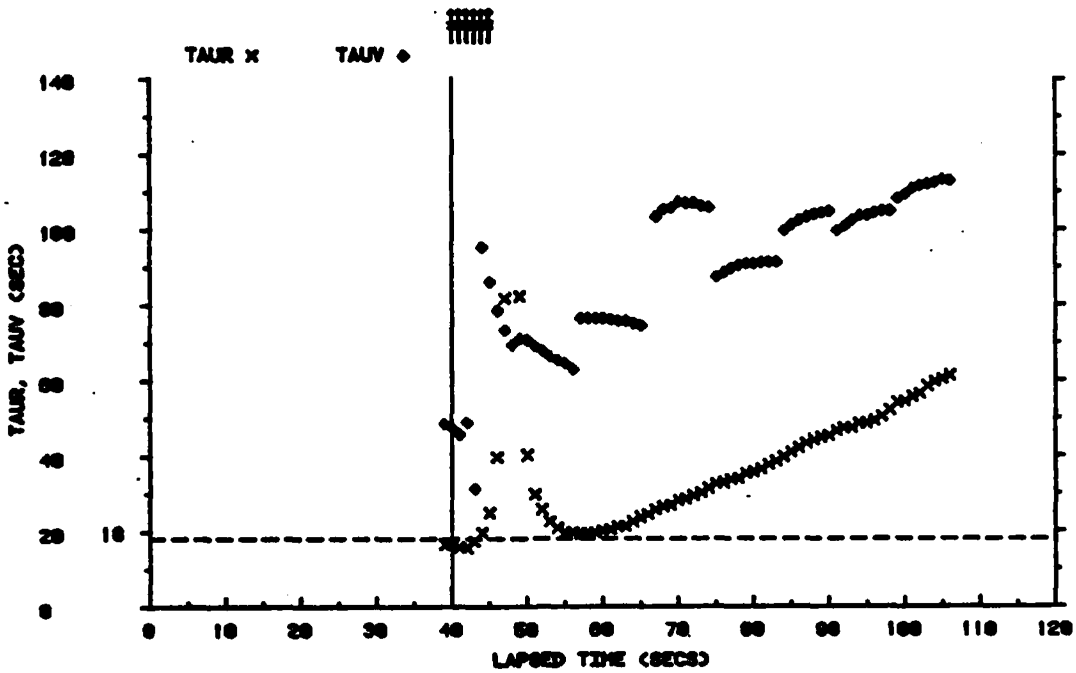


R × RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZOWN + ZINT ◆ R ▲
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

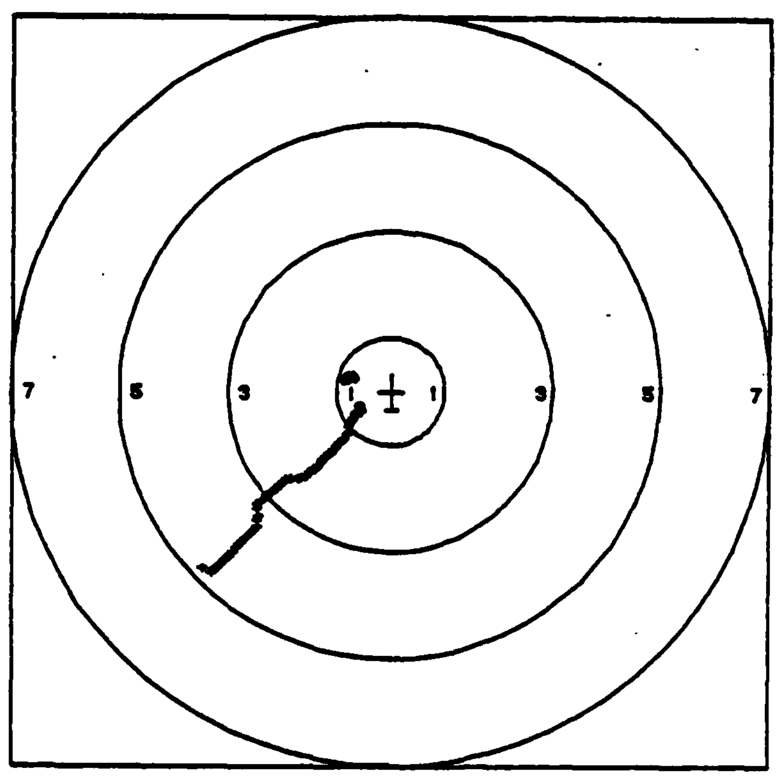
CASE 23

(Tape B060, Intruder 73) Vertical Divergence Case - Don't Climb on Near Level Intruder Above Descending Own Aircraft on Approach

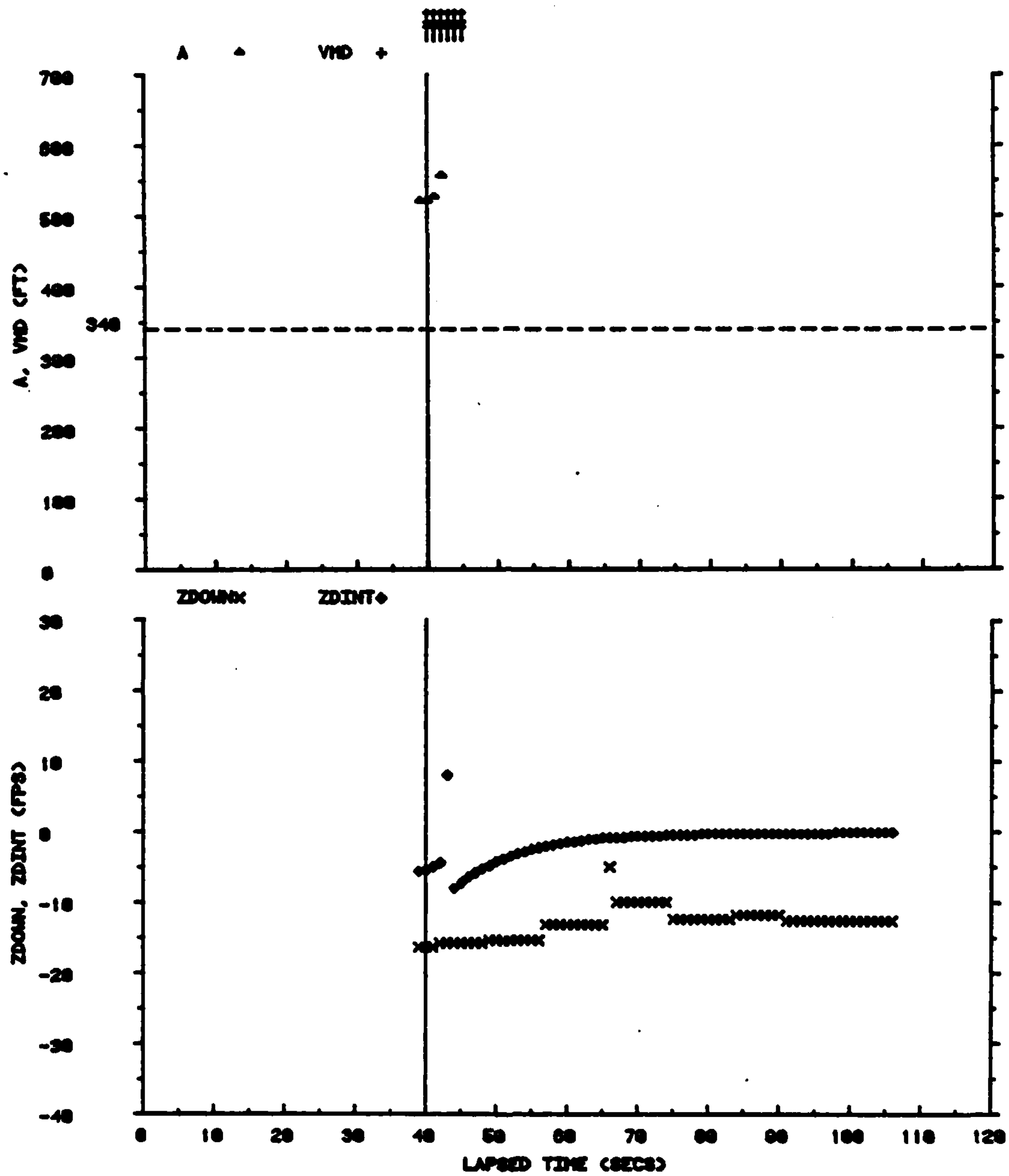
This encounter appears to have been caused by a turn (probably by the test aircraft) when the two aircraft were 0.8 miles apart. The continued turn then placed the two aircraft on diverging courses. Altitude separation at the time of closest approach was 500 feet and increasing. This is typical of terminal area situations.



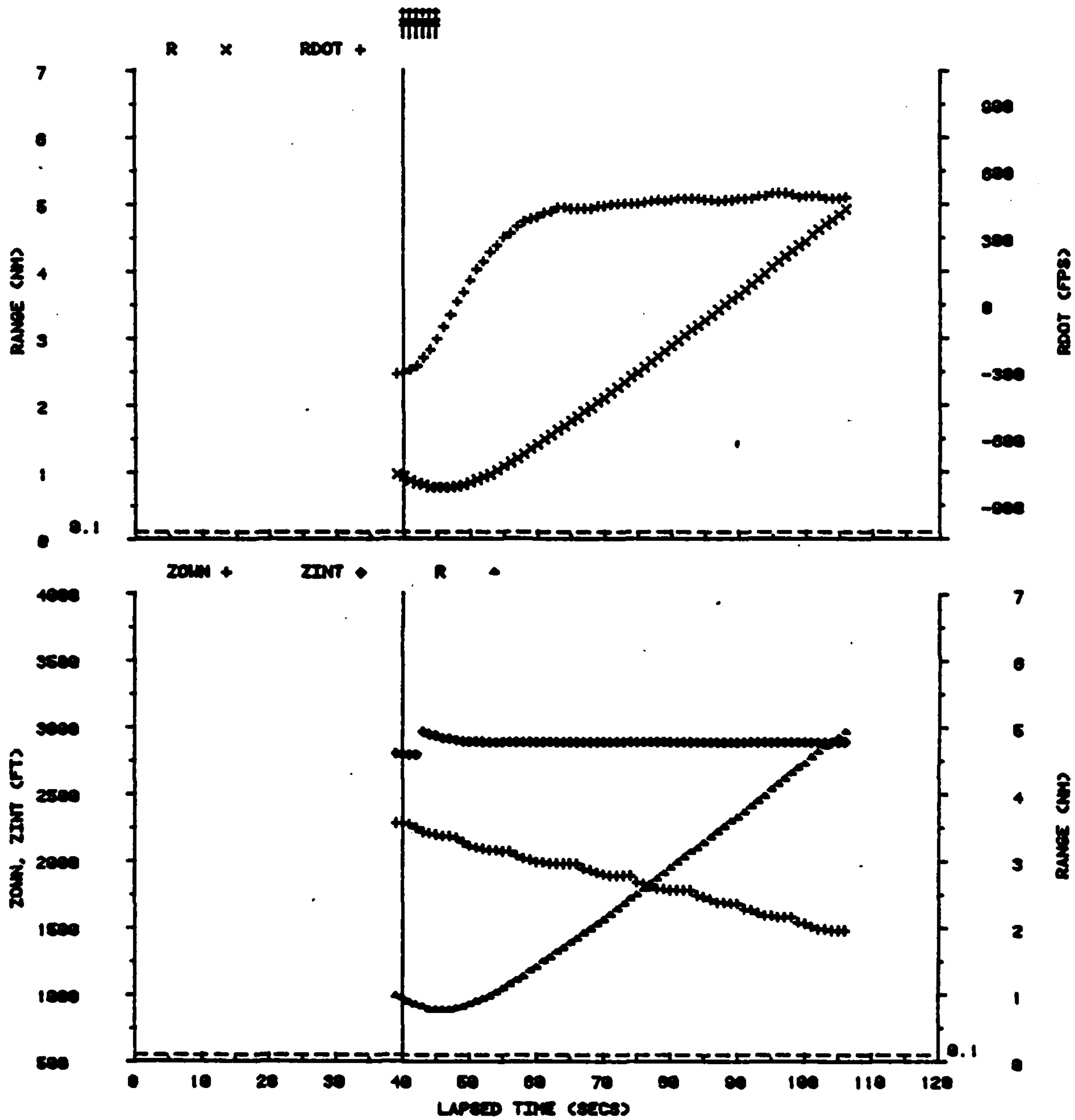
TAUR ×
TAUV ◆
140
120
100
80
60
40
20
0
18
TAUR, TAUV (SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
1
1
3
5
7



A
VMD
700
600
500
400
340
300
200
100
0
A, VMD (FT)
ZDOWN×
ZDINT◆
30
20
10
0
-10
-20
-30
-40
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

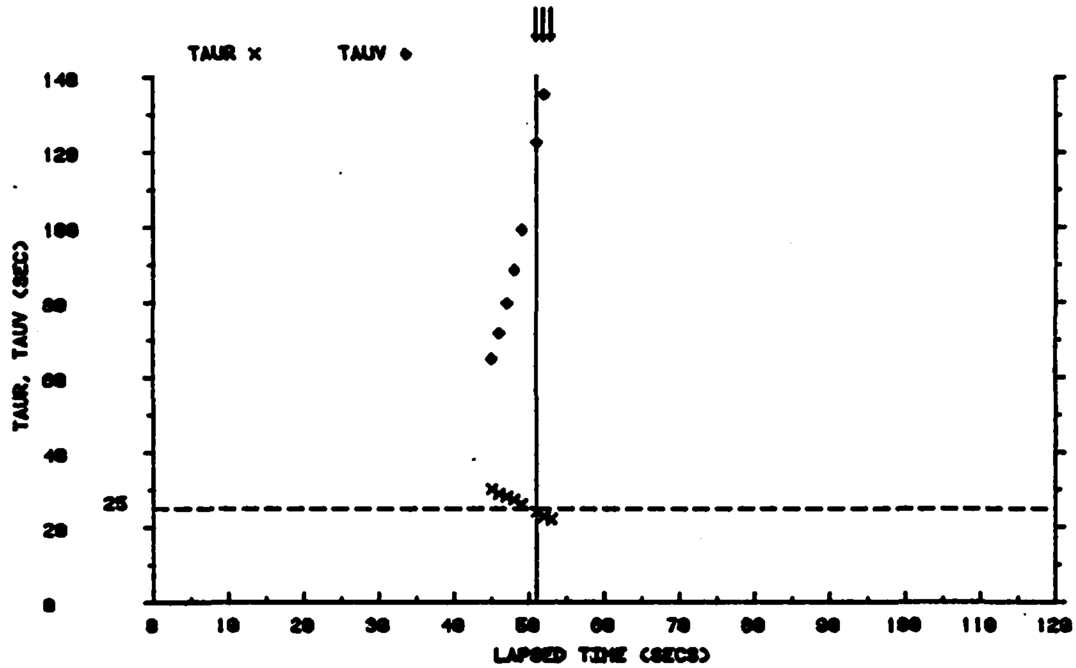


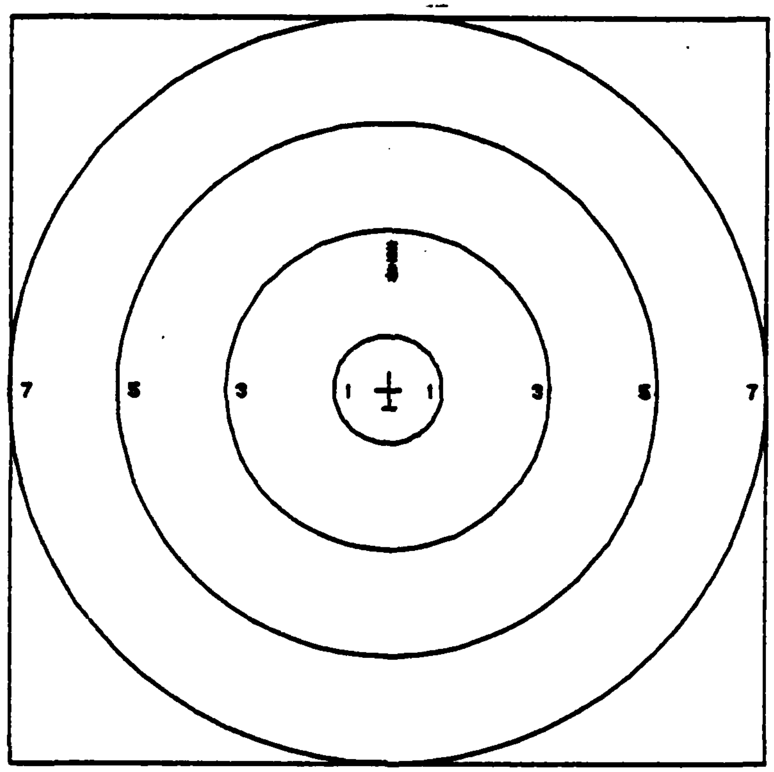
R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.1
ZOWN +
ZINT ◆
R ▲
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

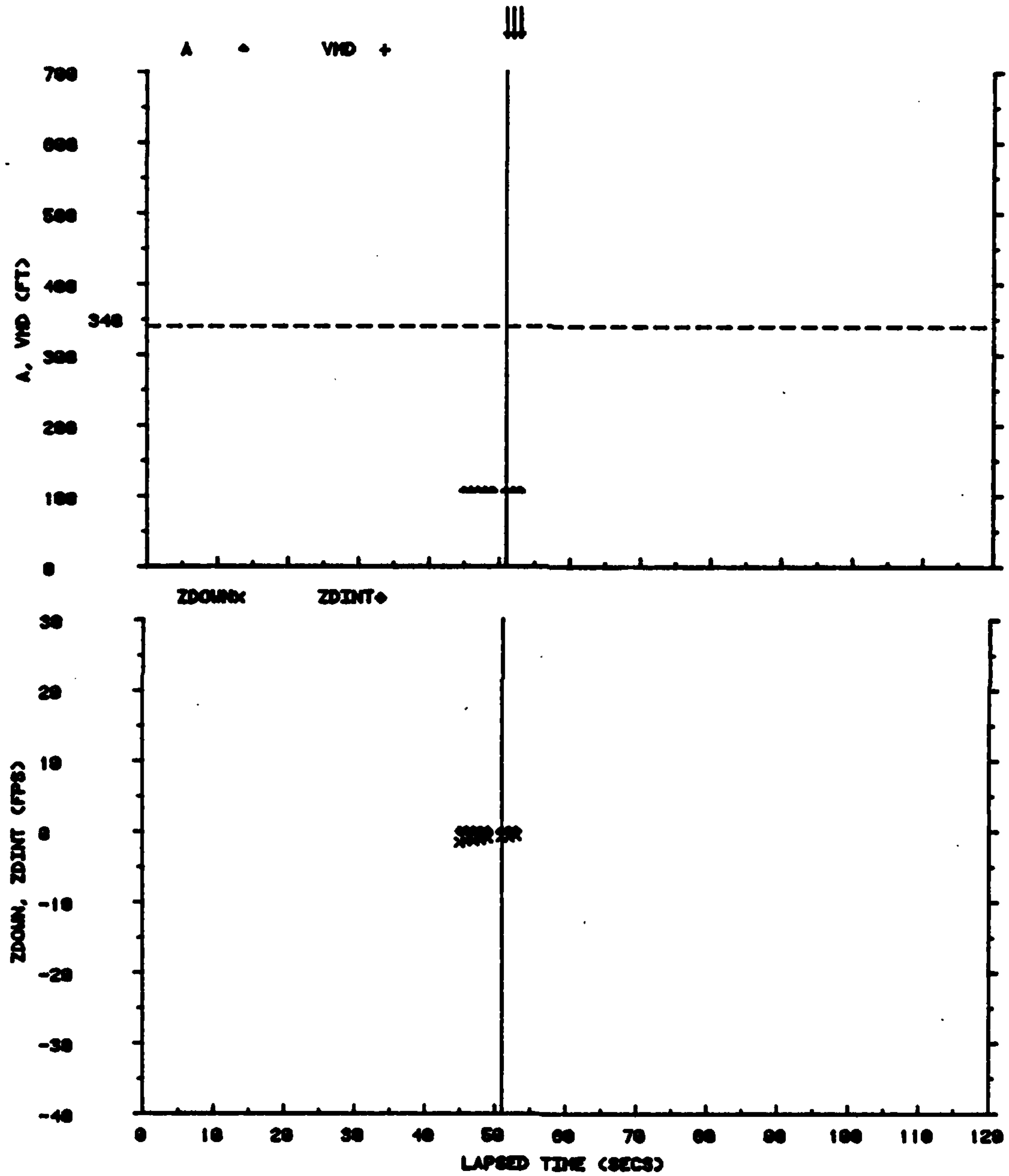
CASE 24

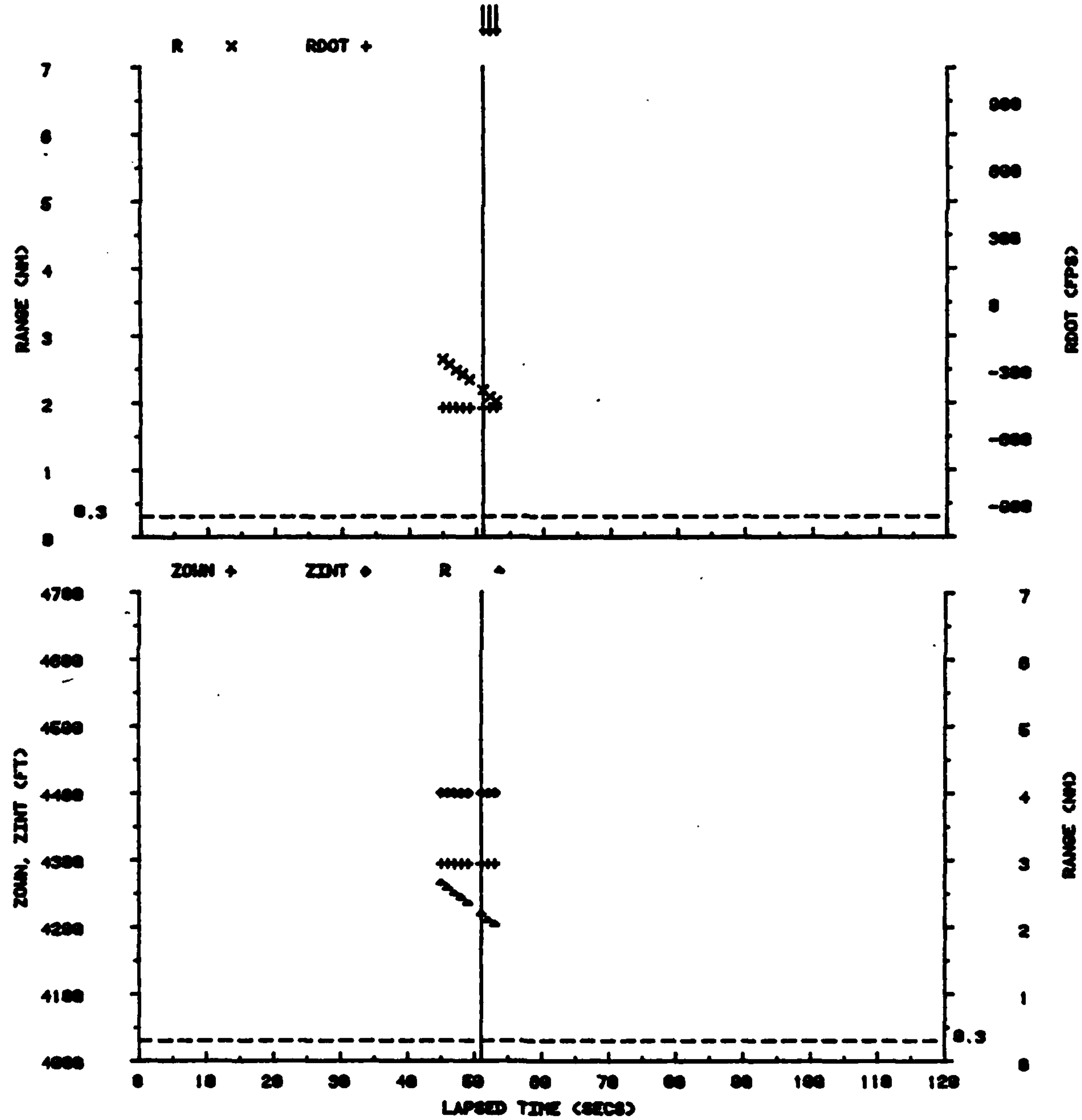
(Tape B062, Intruder 37) Positive Advisory to Descend Cause by Encounter with Head on Intruder

In this encounter both aircraft are in level flight, approximately co-altitude at 4400 feet. The closure rate (360 knots) indicate a head-on encounter. When the two aircraft were at 2 miles range, a 3-second descend advisory was generated. The track was then dropped. This is an anamolous case under investigation by the technical development team.


TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
LAPSED TIME (SECS)
25


7
5
3
1
1
3
5
7

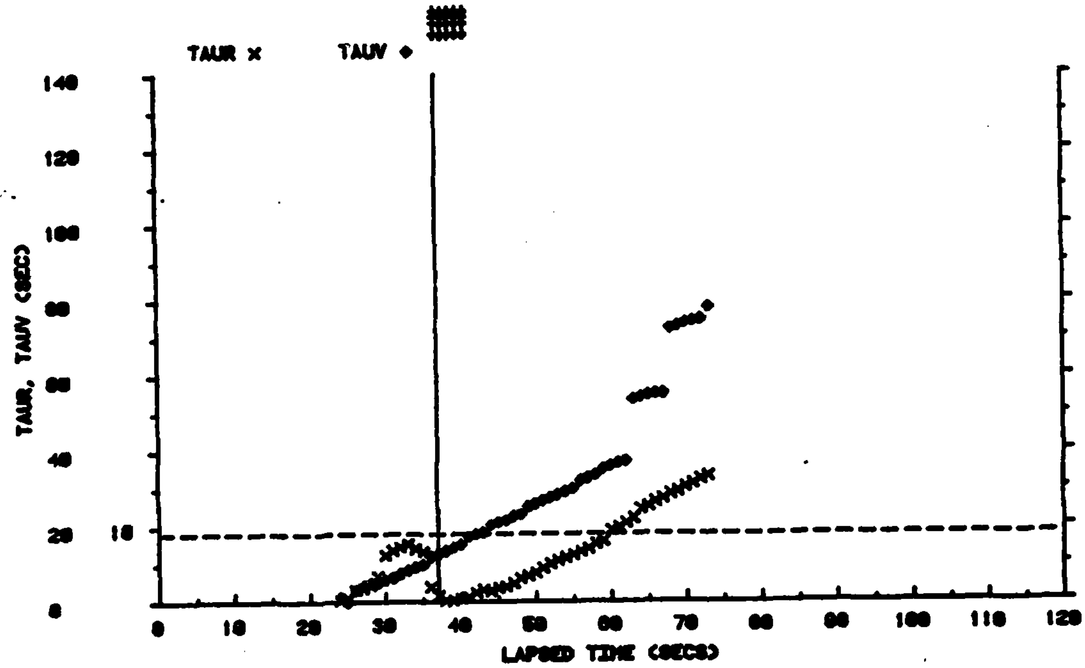

A
VHD
700
600
500
400
340
300
200
100
0
A, VHD (FT)
ZDOWN×
ZDINT◆
30
20
10
0
-10
-20
-30
-40
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)


R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZOWN +
ZINT ◆
R ▲
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

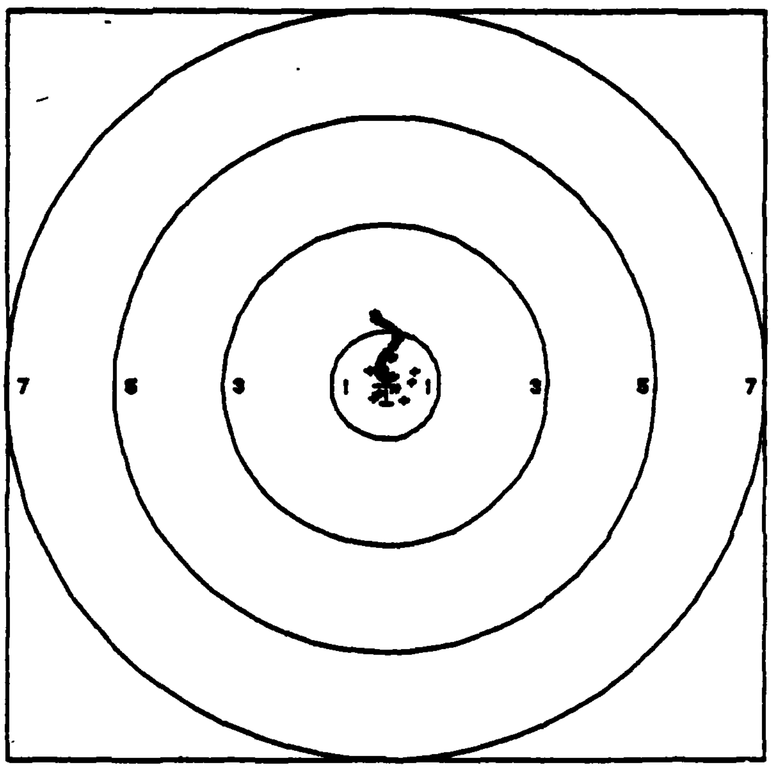
CASE 25

(Tape B062, Intruder 207) Limit Descent (2,000 FPM) on Ground Level Intruder During Takeoff Climb

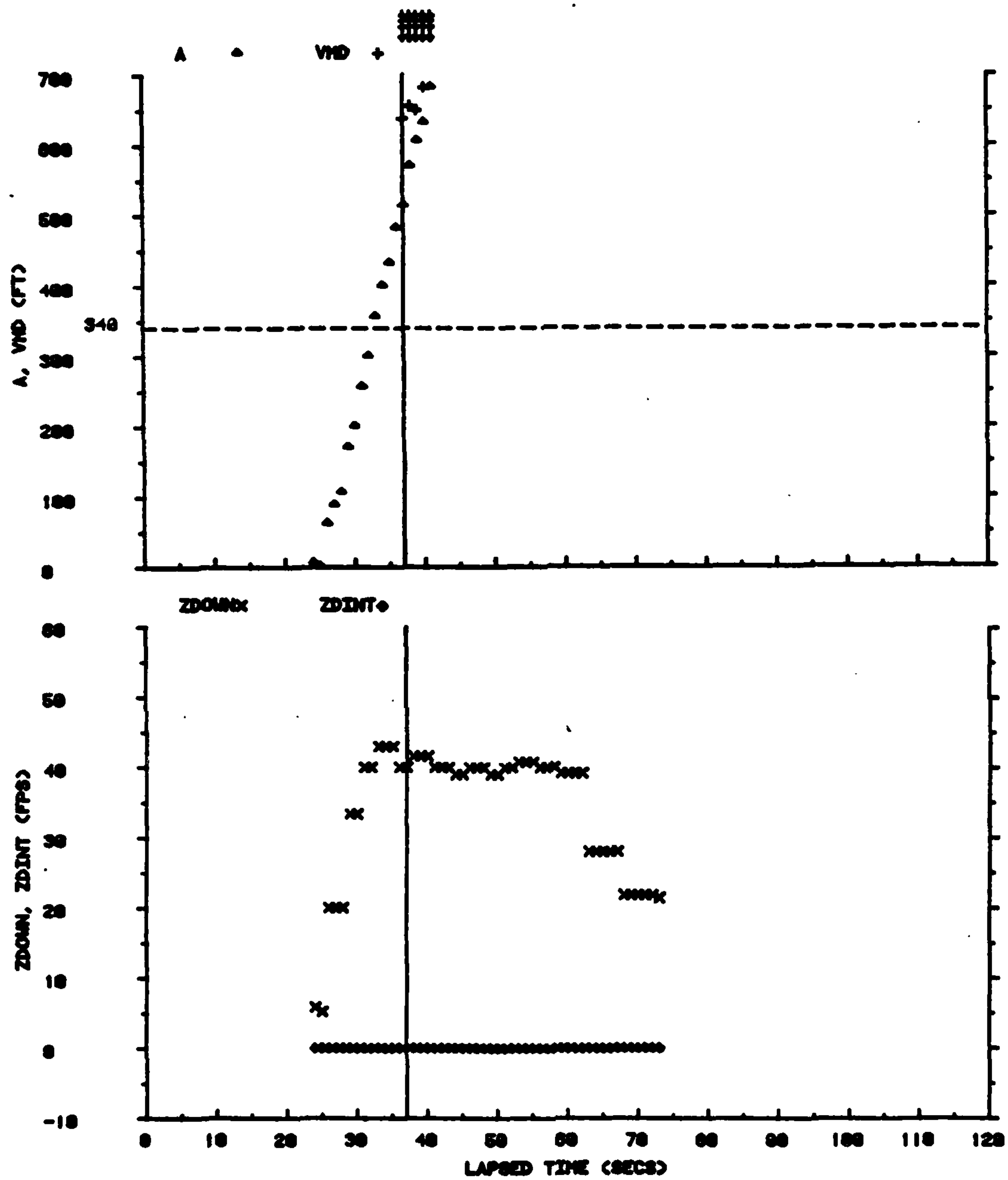
This encounter, caused by an on-ground aircraft, occurred during takeoff and involved a turn, possibly back across the airport as the test aircraft continued to climb. The LIMIT DESCENT advisory was compatible with the climb that was being executed by the test aircraft.

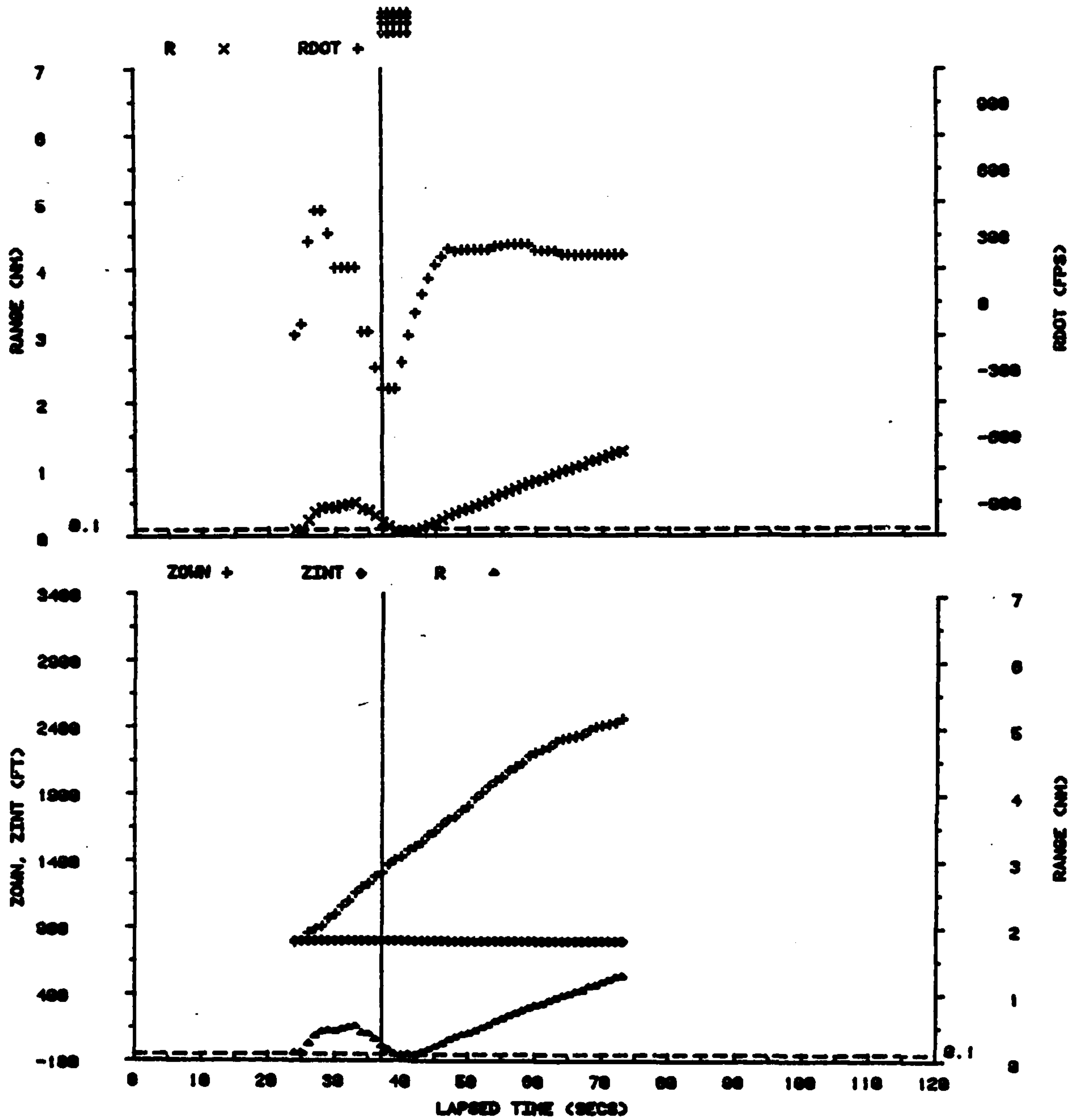


TAUR ×
TAUV ◆
140
120
100
80
60
40
20
0
18
TAUR, TAUV (SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
1
1
3
5
7


A
VHD +
A, VHD (FT)
340
ZDOWN×
ZDINT◆
ZDOWN, ZDINT (FPS)
LAPSED TIME (SECS)

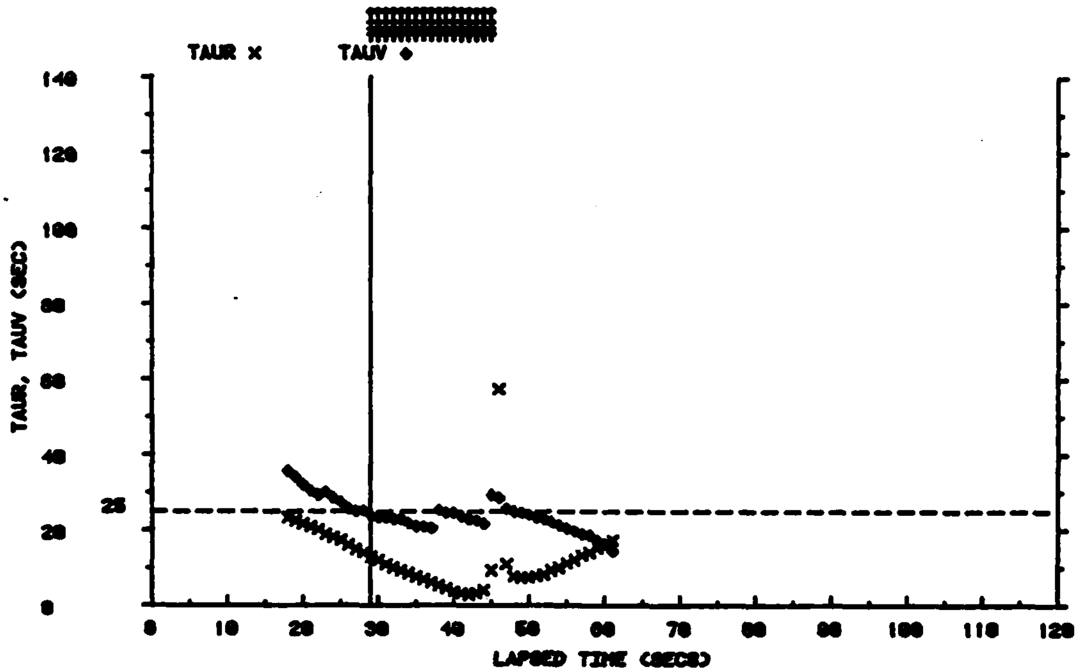


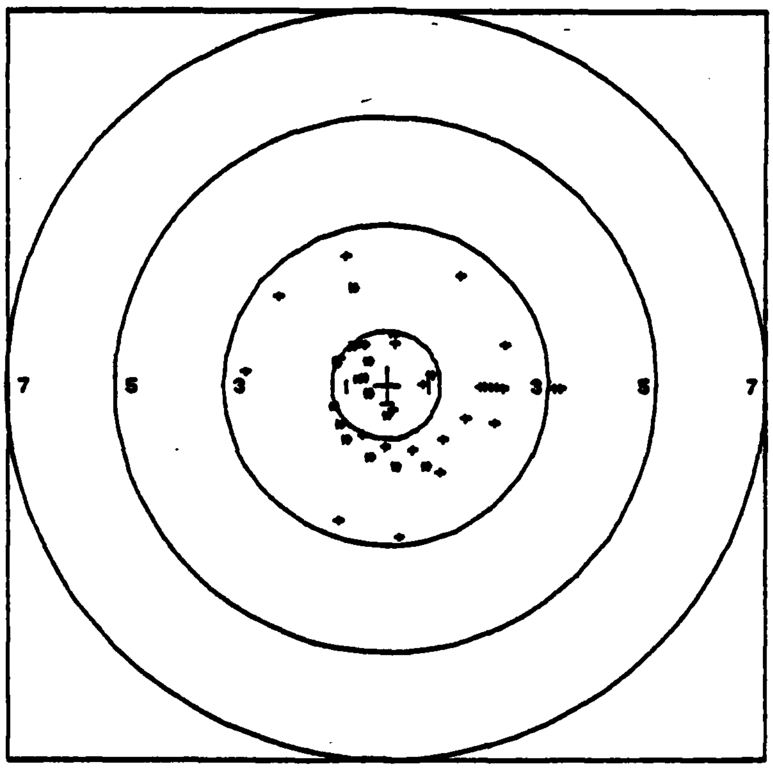
R ×
RDOT +
RANGE (NM)
RDOT (FPS)
ZDWN +
ZINT ◆
R ▲
ZDWN, ZINT (FT)
RANGE (NM)
0.1
LAPSED TIME (SECS)

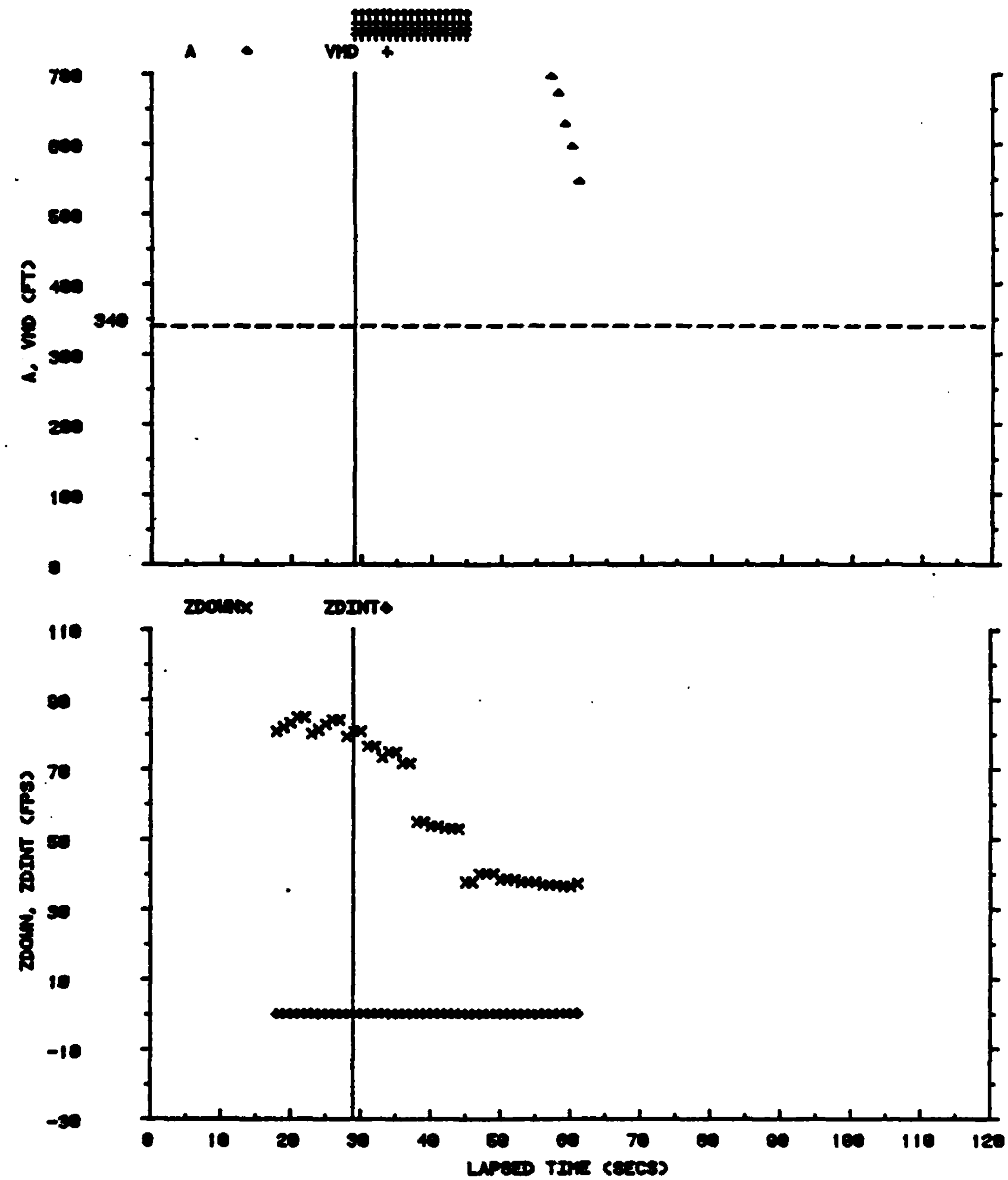
CASE 26

(Tape B062, Intruder 179) Limit Climb (2,000 FPM) on Level Intruder Above with Own Aircraft on Departure Climb

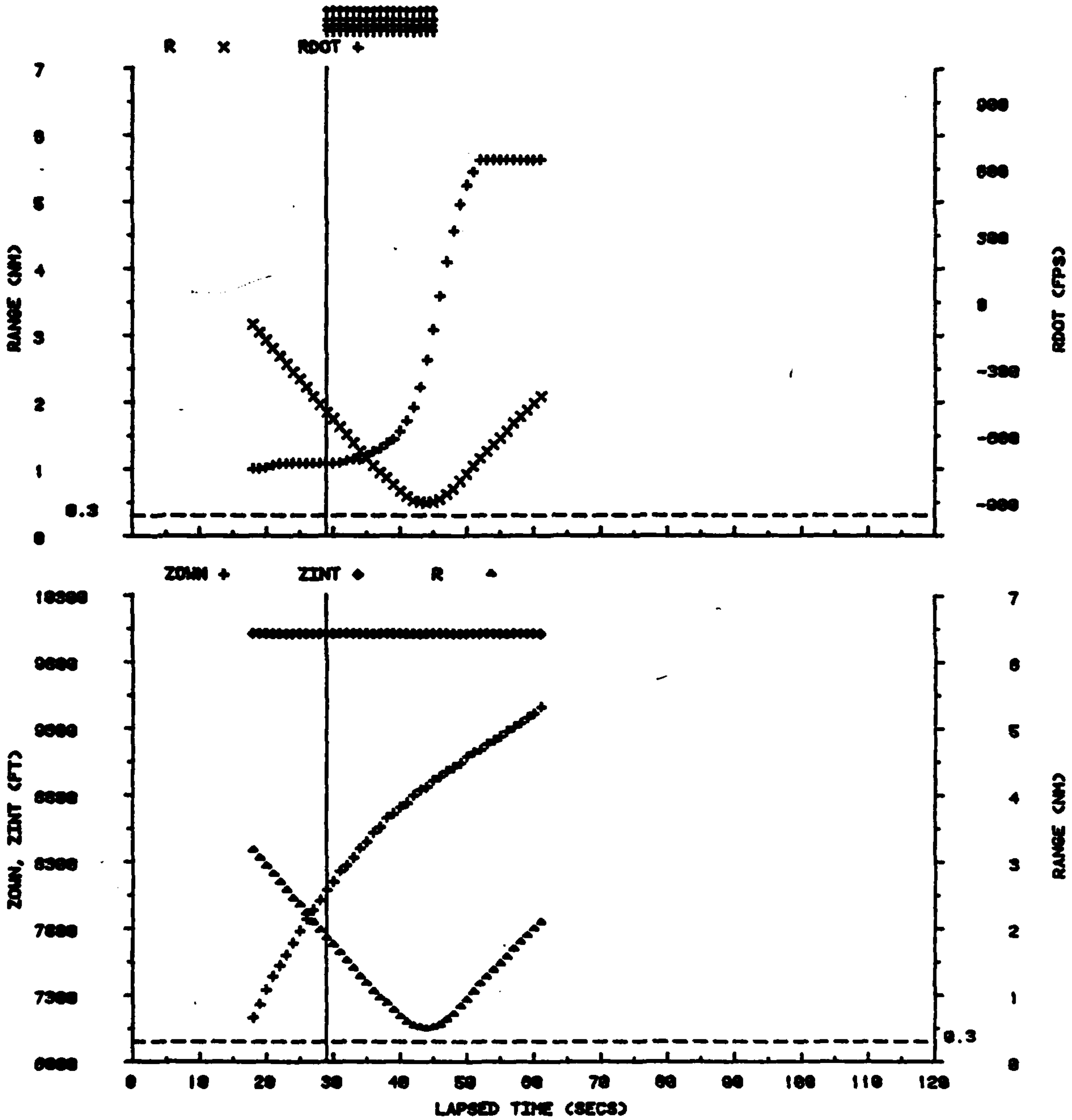
This encounter shows the test aircraft climbing toward the intruder altitude. At the time the two aircraft are at their minimum range of 0.5 miles, they have more than 1000 feet separation; therefore the limit climb advisory was acceptable. The test aircraft was climbing at 4800 feet per miniute (FPM) at the time the advisory was given, and its vertical rate decayed to 2100 FPM at the time the advisory was terminated.


TAUR ×
TAUV ◆
140
120
100
80
60
40
25
20
0
TAUR, TAUV (SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)


7
5
3
1
1
3
5
7



A
VMD
700
600
500
400
340
300
200
100
0
A, VMD (FT)
ZDOWN
ZDINT
110
90
70
50
30
10
-10
-30
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)

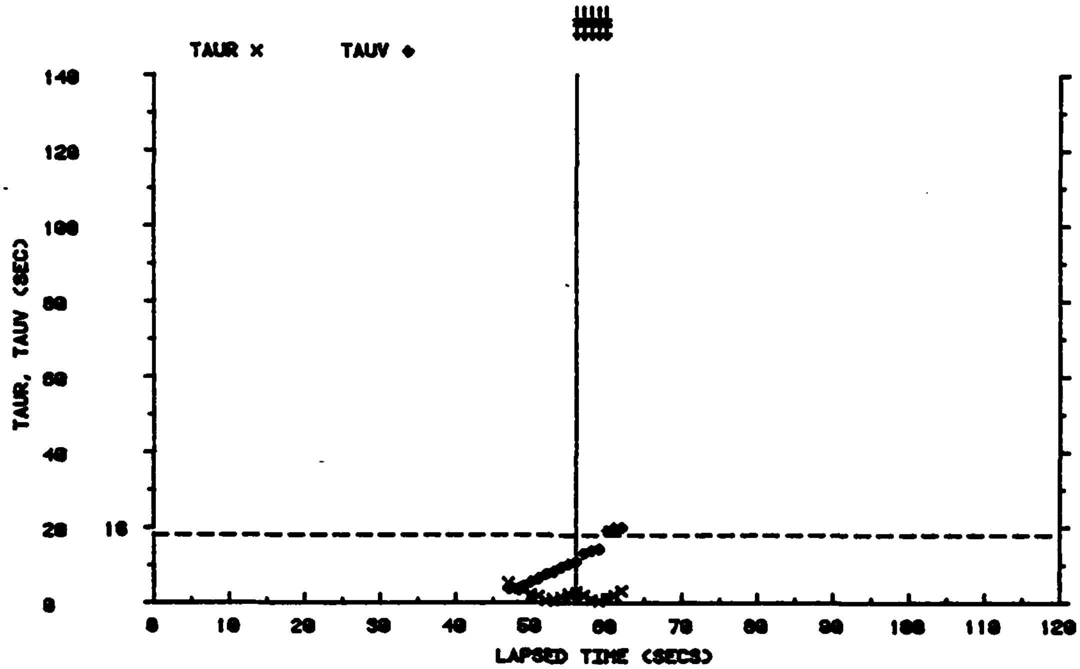


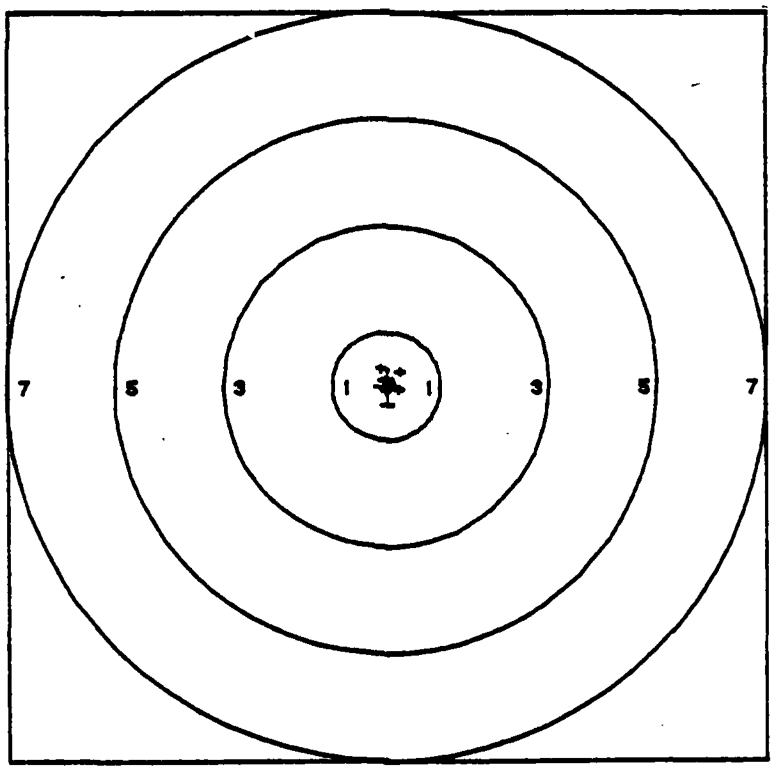
R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZOWN +
ZINT ◆
R ▲
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

CASE 27

(Tape B062, Intruder 206) Don't Descend on Ground Level Intruder During Own Aircraft Takeoff

Own aircraft took off and climbed past a ground level target. Upon reaching 500 feet above ground level (AGL), TCAS performance level changed from 2 to 4 where resolution advisories were no longer inhibited. Own aircraft climb was compatible with the unnecessary advisory on a ground level intruder.


TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
LAPSED TIME (SECS)
16


7 5 3 1 1 3 5 7

AD-A146 435 IN-SERVICE EVALUATION OF THE DALMO VICTOR ACTIVE BEACON COLLISION AVOIDAN..(U) ARINC RESEARCH CORP ANNAPOLIS MD T P BERRY ET AL. OCT 82 1391-01-1-2810 DOT/FAA/RD-82/90 3/3

UNCLASSIFIED DTFA01-80-C-10093 F/G 17/7 NL

END

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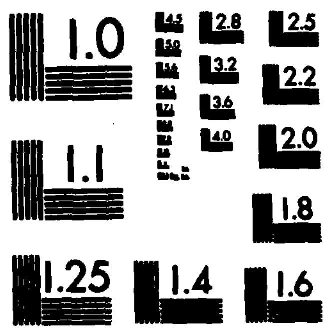
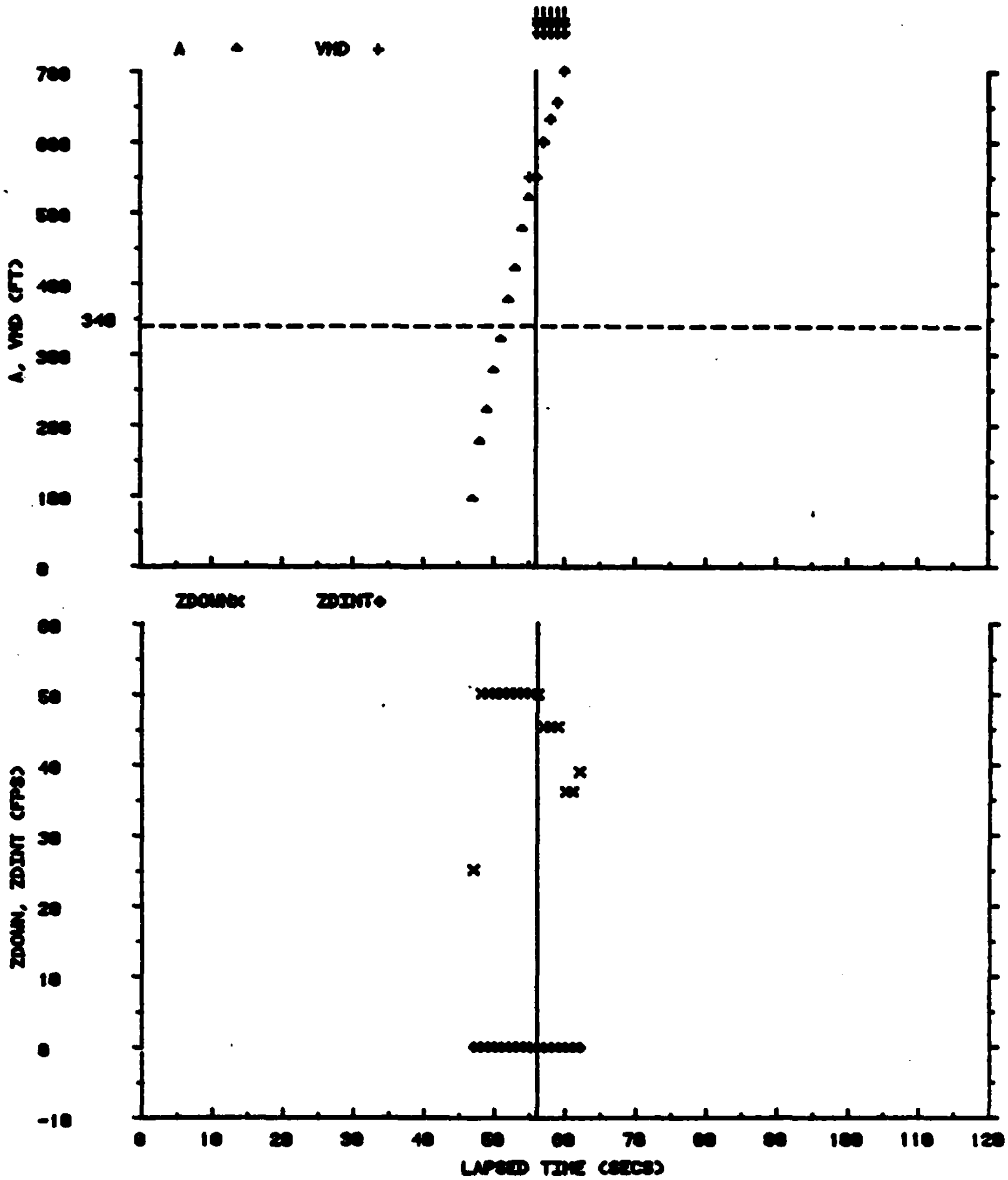
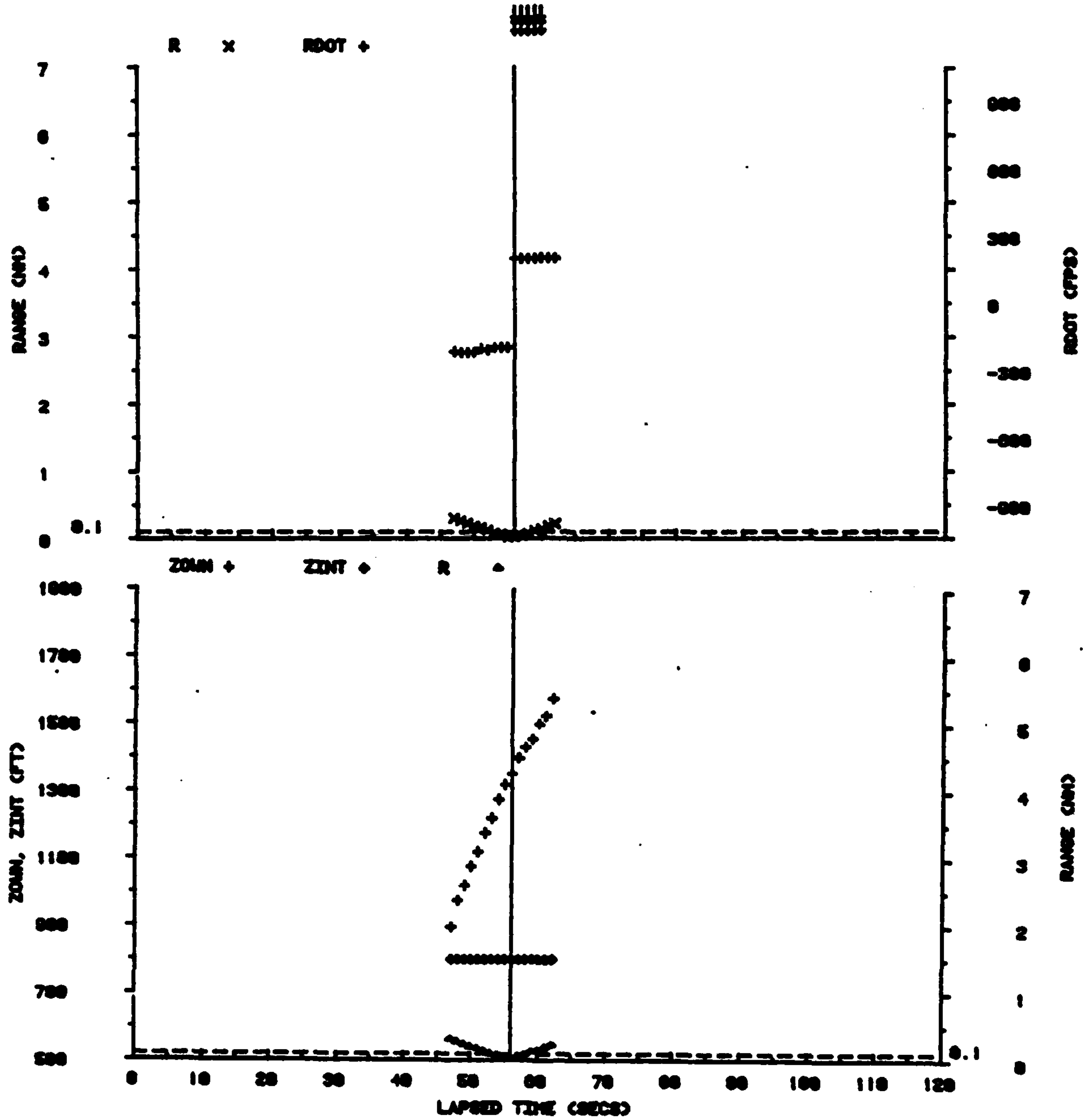


MICROCOPY RESOLUTION TEST CHART


A
VHD
A, VHD (FT)
340
ZDOWN×
ZDINT◆
ZDOWN, ZDINT (FPS)
LAPSED TIME (SECS)

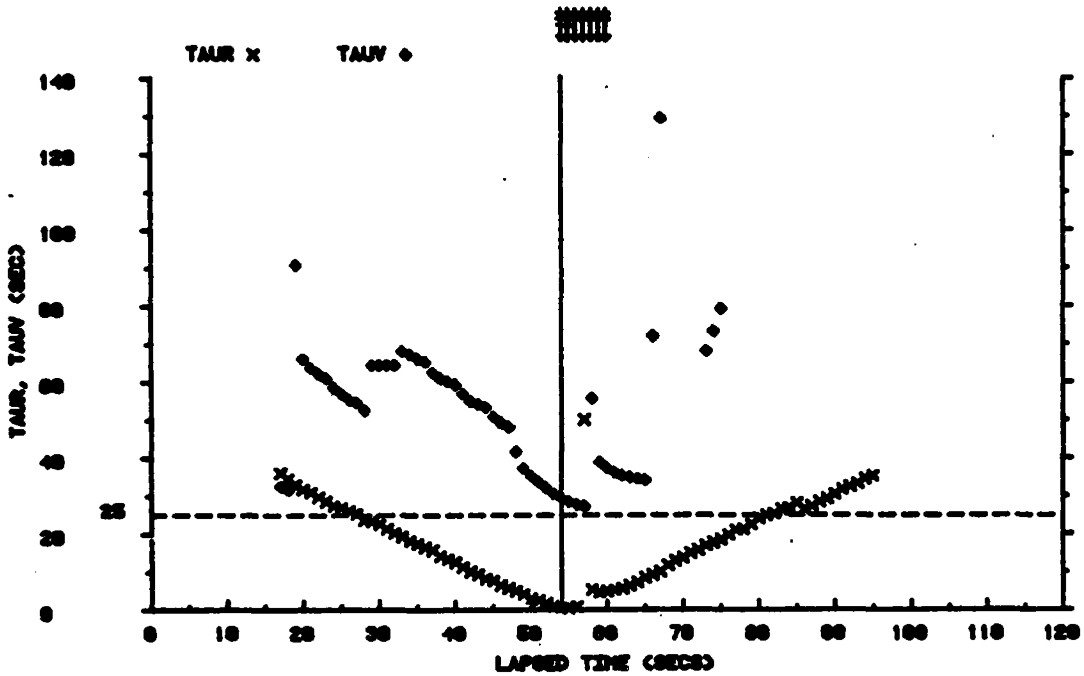


R x ROOT +
RANGE (NM)
RDOT (FPS)
0.1
ZOWN + ZINT ◆ R ▲
ZOWN, ZINT (FT)
RANGE (NM)
0.1
0 10 20 30 40 50 60 70 80 90 100 110 120
LAPSED TIME (SECS)

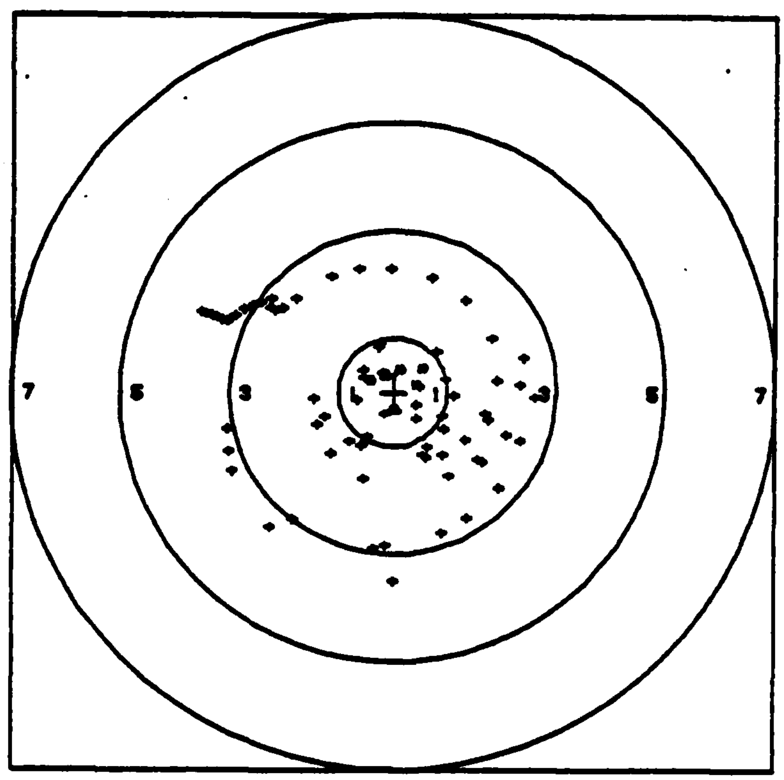
CASE 28

(Tape B062, Intruder 77) Transition Limit Descents (2,000 FPM/ 1,000 FPM) on Level Airborne Intruder Below on Approach

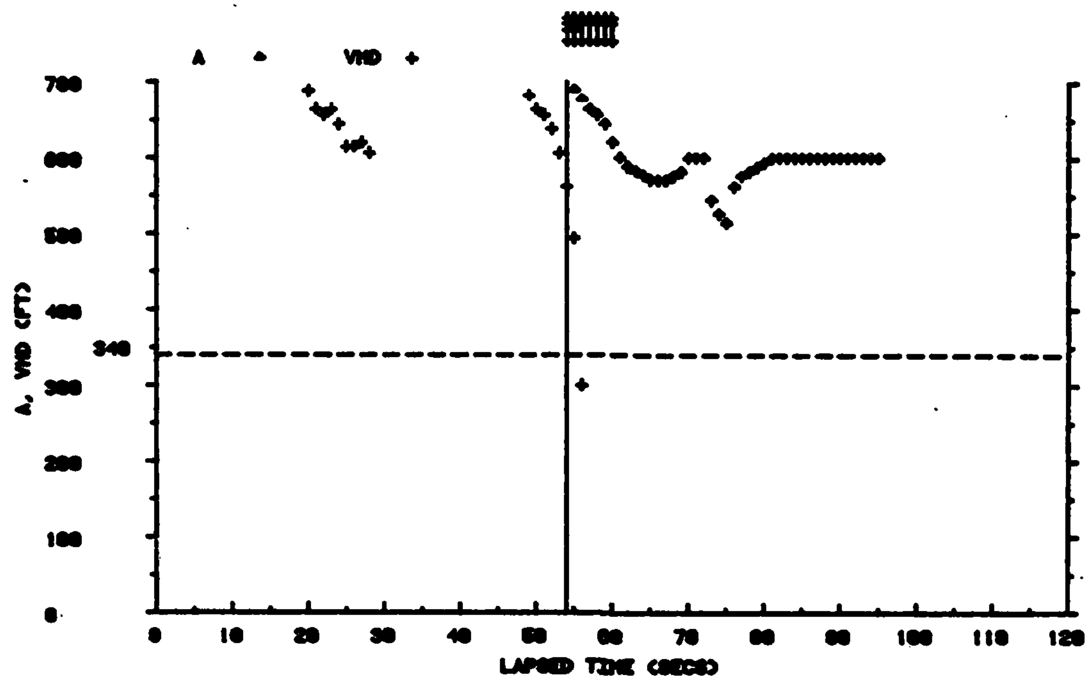
In this encounter, the test aircraft is leveling from a slow descent (1500 FPM) approximately 700 feet above the intruder. The minimum range was 0.3 miles with a closure rate of 360 knots, which indicates an opposite direction encounter.

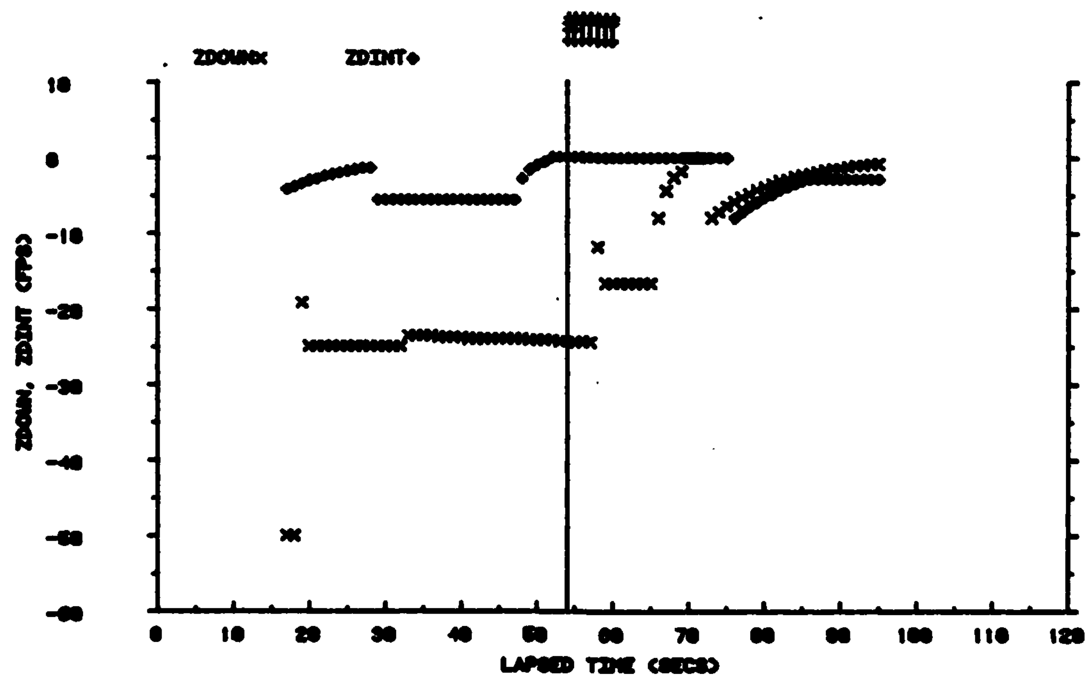


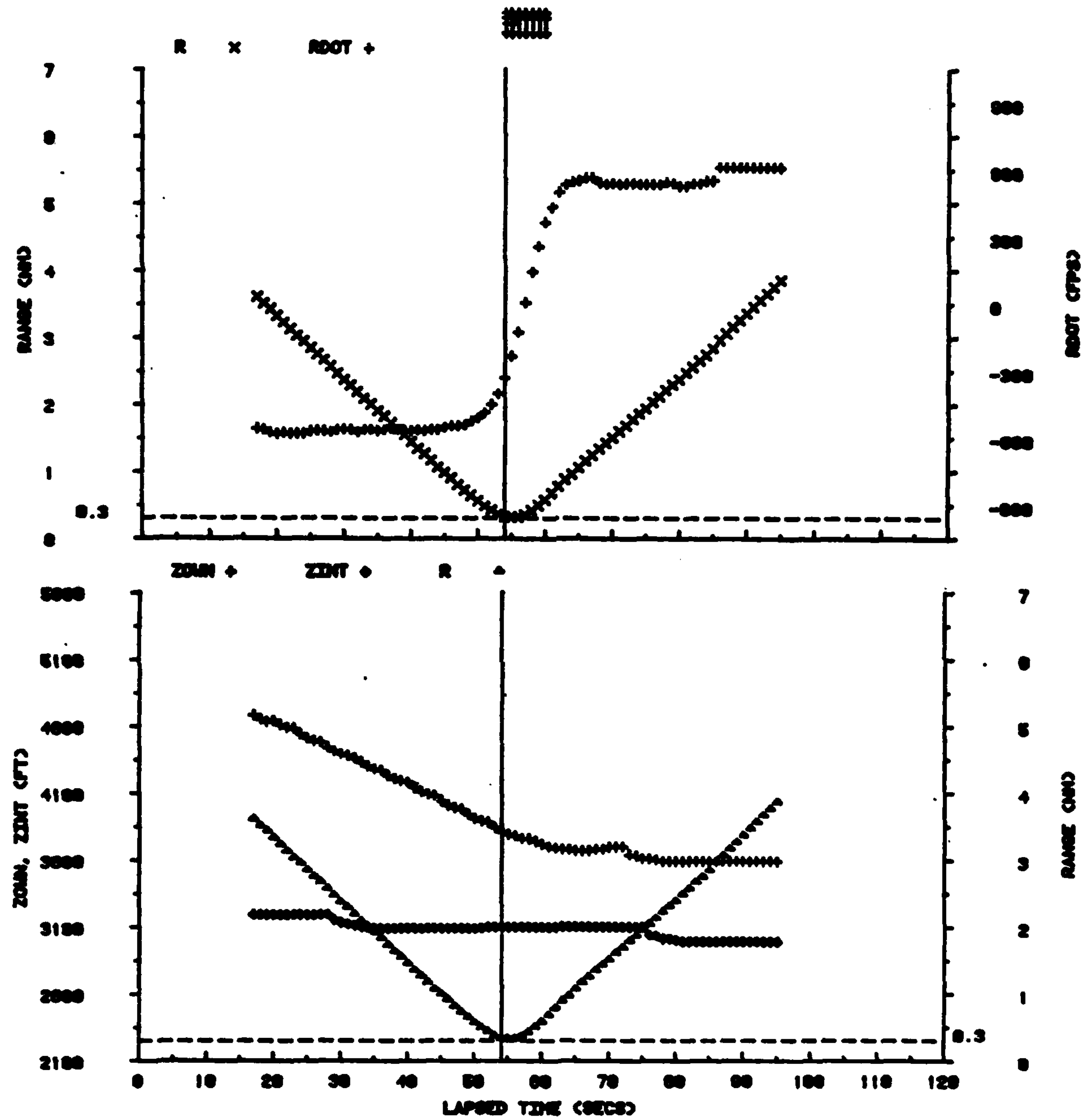
TAUR x
TAUV ◆
140
120
100
80
60
40
25
20
0
TAUR, TAUV (SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
1
1
3
5
7


A
VMD
A, VMD (FT)
340
LAPSED TIME (SECS)


ZDOWN×
ZDINT◆
ZDOWN, ZDINT (FPS)
LAPSED TIME (SECS)



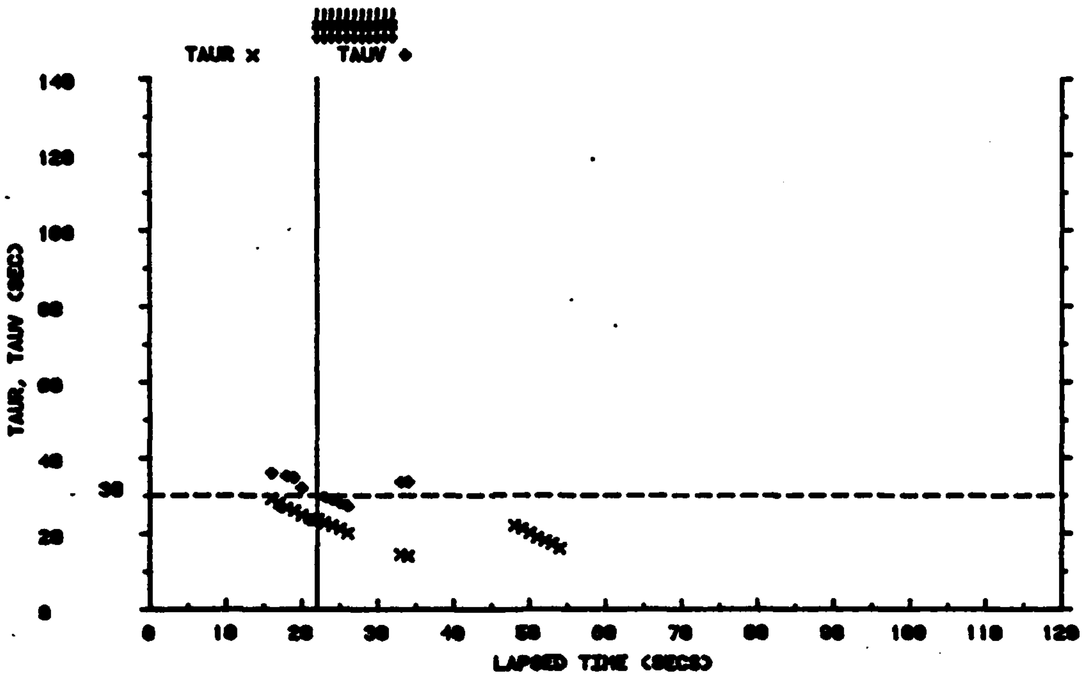
R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZOWN +
ZINT ◆
R ▲
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

CASE 29

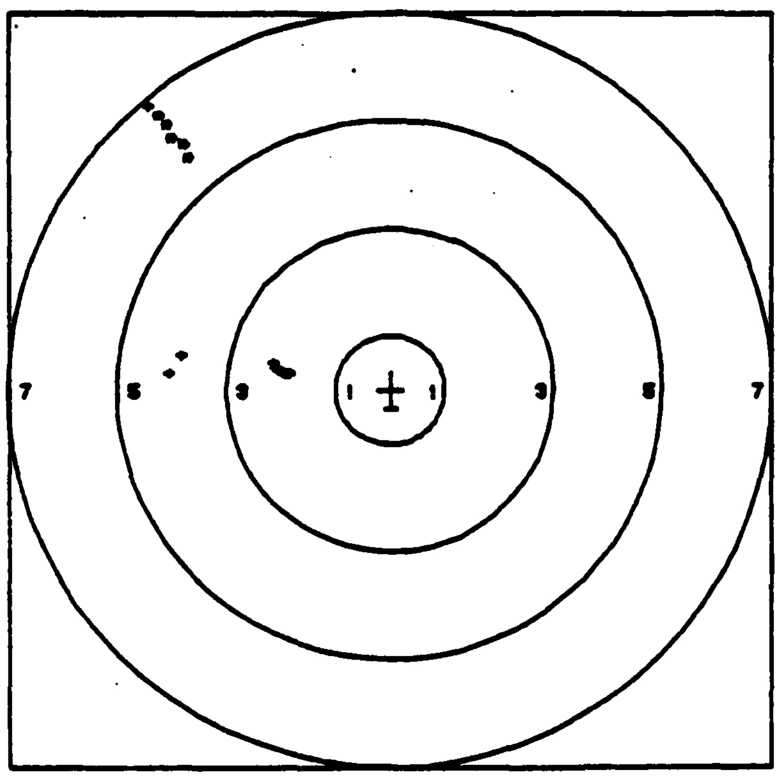
(Tape A063, Intruder 57) Negative Don't Descend on Intruder Below Own Aircraft with High Closure En Route

This en route encounter at FL 250 with an intruder at FL 240 was initiated by a descent of the test aircraft to level at FL 250. The initial descent rate of the test aircraft is in excess of 3500 FPM, setting up the DON'T DESCEND advisory. When the test aircraft leveled, the advisory was cancelled.

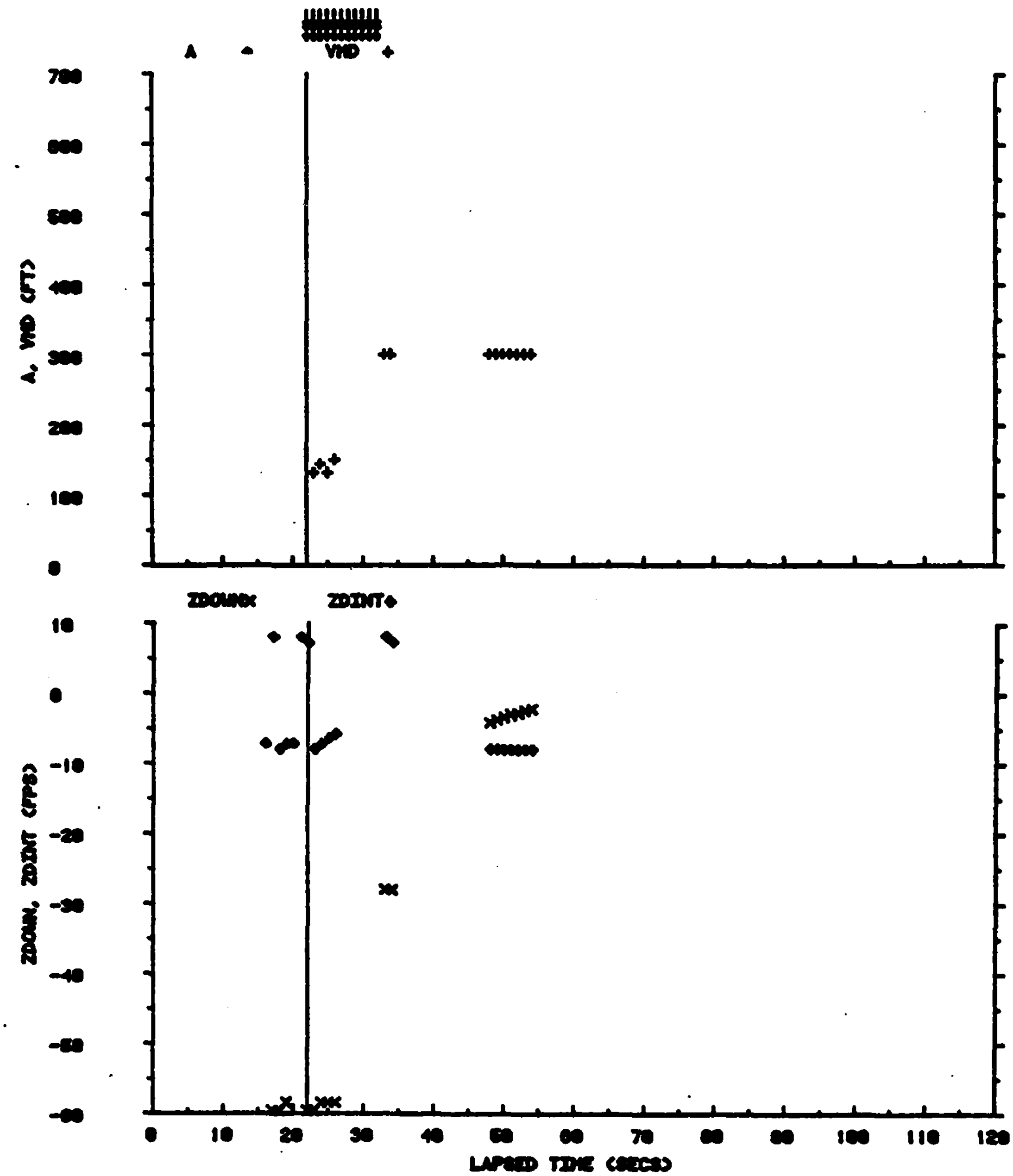
There are two data gaps apparent in this event -- a 5 second gap at time 28-33, and a 13 second gap at time 35-48 seconds.

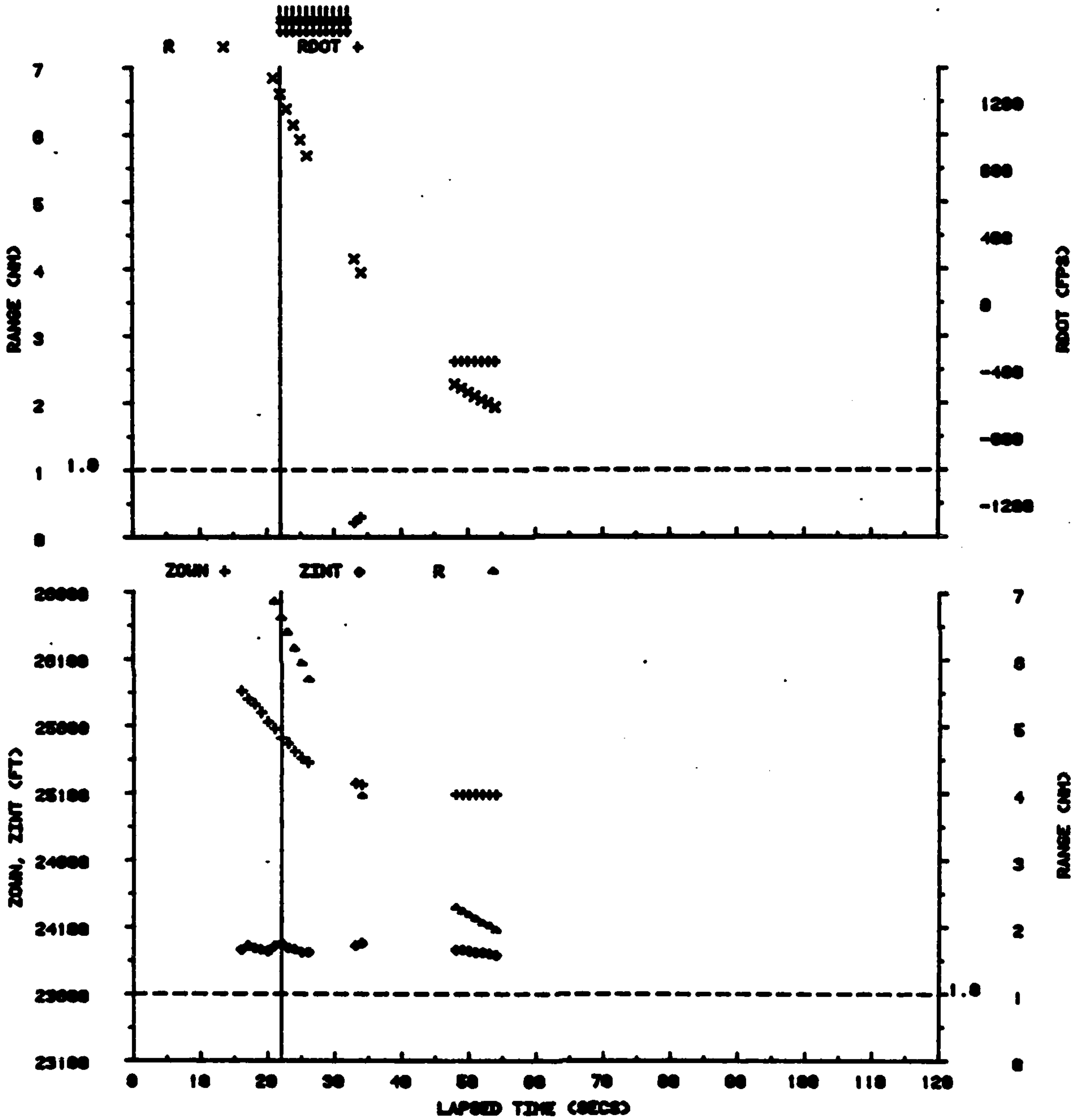


TAUR ×
TAUV ◆
140
120
100
80
60
40
30
20
0
TAUR, TAUV (SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
1
1
3
5
7


A
VHD
A, VHD (FT)
ZDOWN×
ZDINT◆
ZDOWN, ZDINT (FPS)
LAPSED TIME (SECS)



R ×
RDOT +
RANGE (NM)
RDOT (FPS)
1.0
ZDWN +
ZINT ◆
R ▲
ZDWN, ZINT (FT)
RANGE (NM)
1.0
LAPSED TIME (SECS)

CASE 30

(Tape B064, Intruder 201) Approach to Denver, March 24, 1982

An ARINC observer was aboard Piedmont Flight 64 landing at Denver, Colorado. At approximately 2:52 p.m. local time, Flight 604 was about two miles out on approach to runway 35R in strong winds and rapidly deteriorating weather conditions as the leading edge of a dust storm moved down the duty runway. Flight 604 was about to pass over and perpendicular to parallel east-west runways at the south side of the field (See Figure B-1), when a traffic advisory target merged with own aircraft symbol and was displayed. This was followed shortly by a resolution advisory of DON'T DESCEND on the TCAS IVSI. Marginal visual conditions precluded visual acquisition of the aircraft and no traffic was called by the tower.

In the opinion of the observer the intruder was an aircraft on the ground in the vicinity of runways 9-27 L and R at the south side of the airfield and the advisory information was unnecessary and of no value. Denver is an example of an airfield consiting of dispersed runways with landing patterns placing landing aircraft in excess of 500 feet over inactive or active alternate runways. In this test the threshold for inhibiting resolution advisories was set at 500 feet.

With altitude separation and projected vertical miss distance with thresholds on the ground level intruder a threat was declared and negative advisory to limit descent (500 FPM) displayed when range TAU fell within the 18 second threshold for performance level 4.

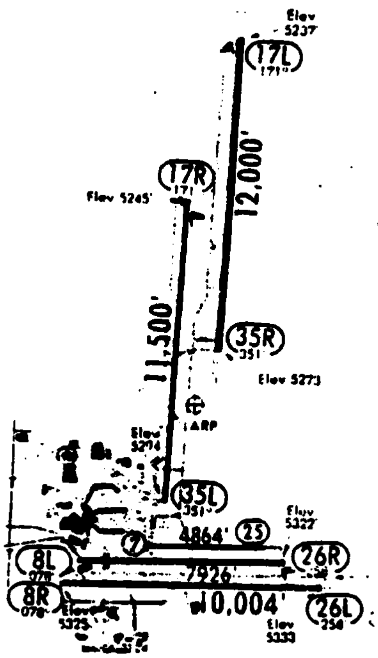
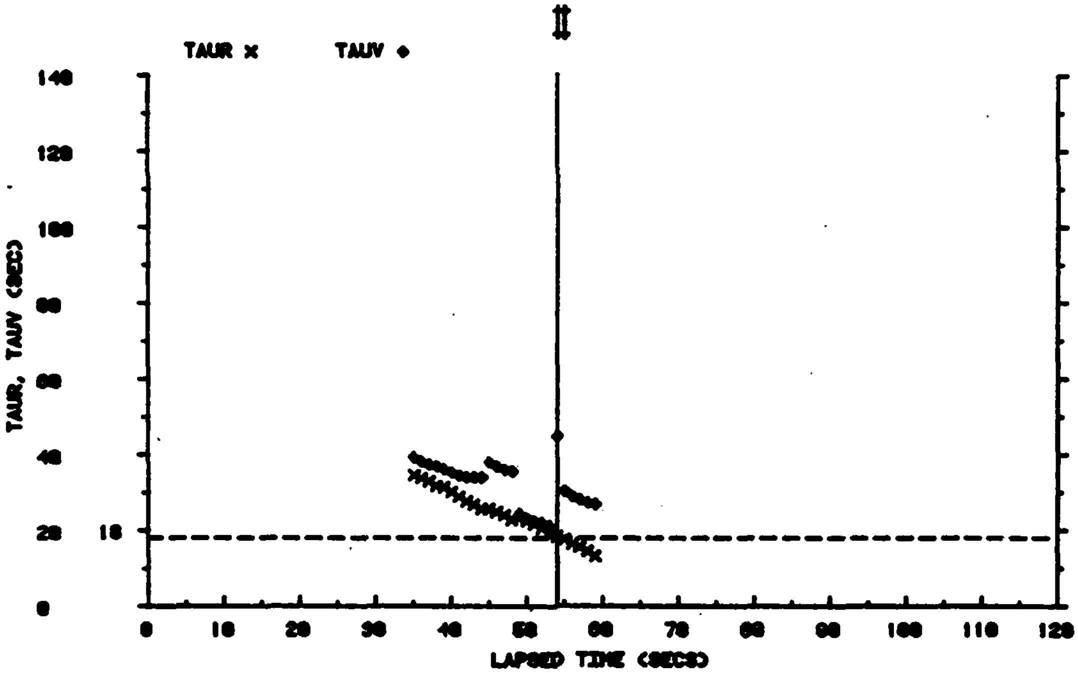
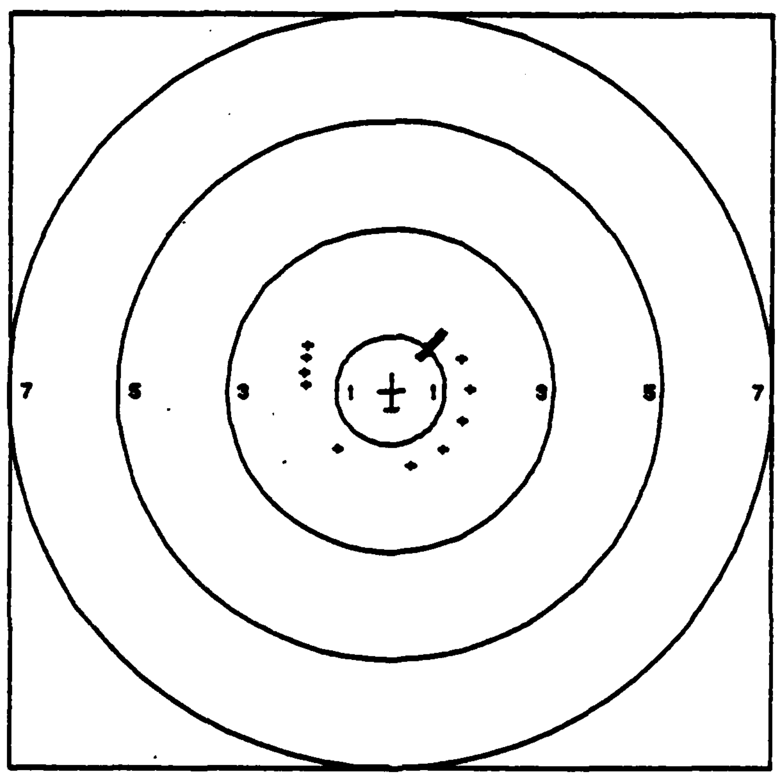


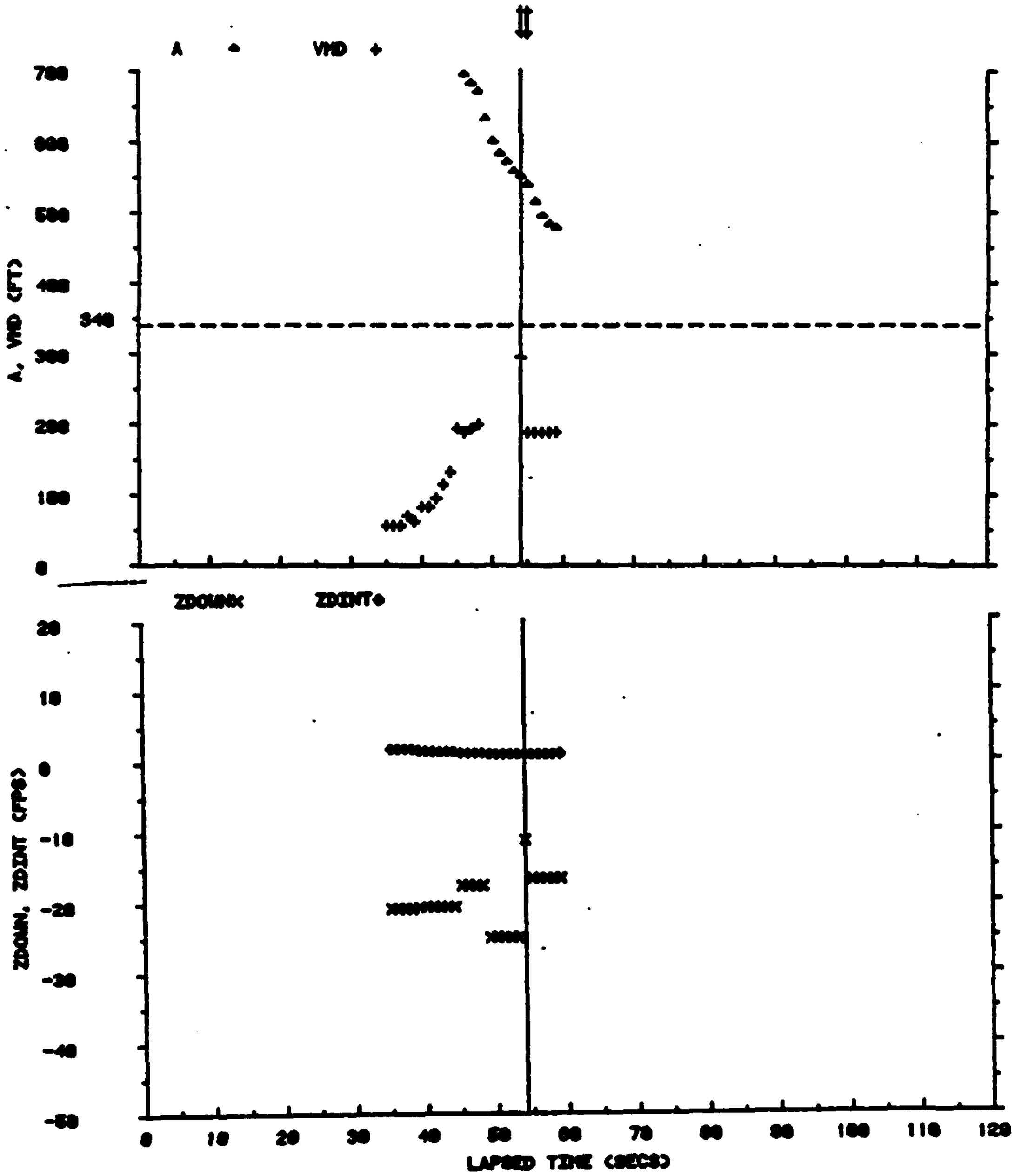
FIGURE B-1. DENVER AIRPORT LAYOUT

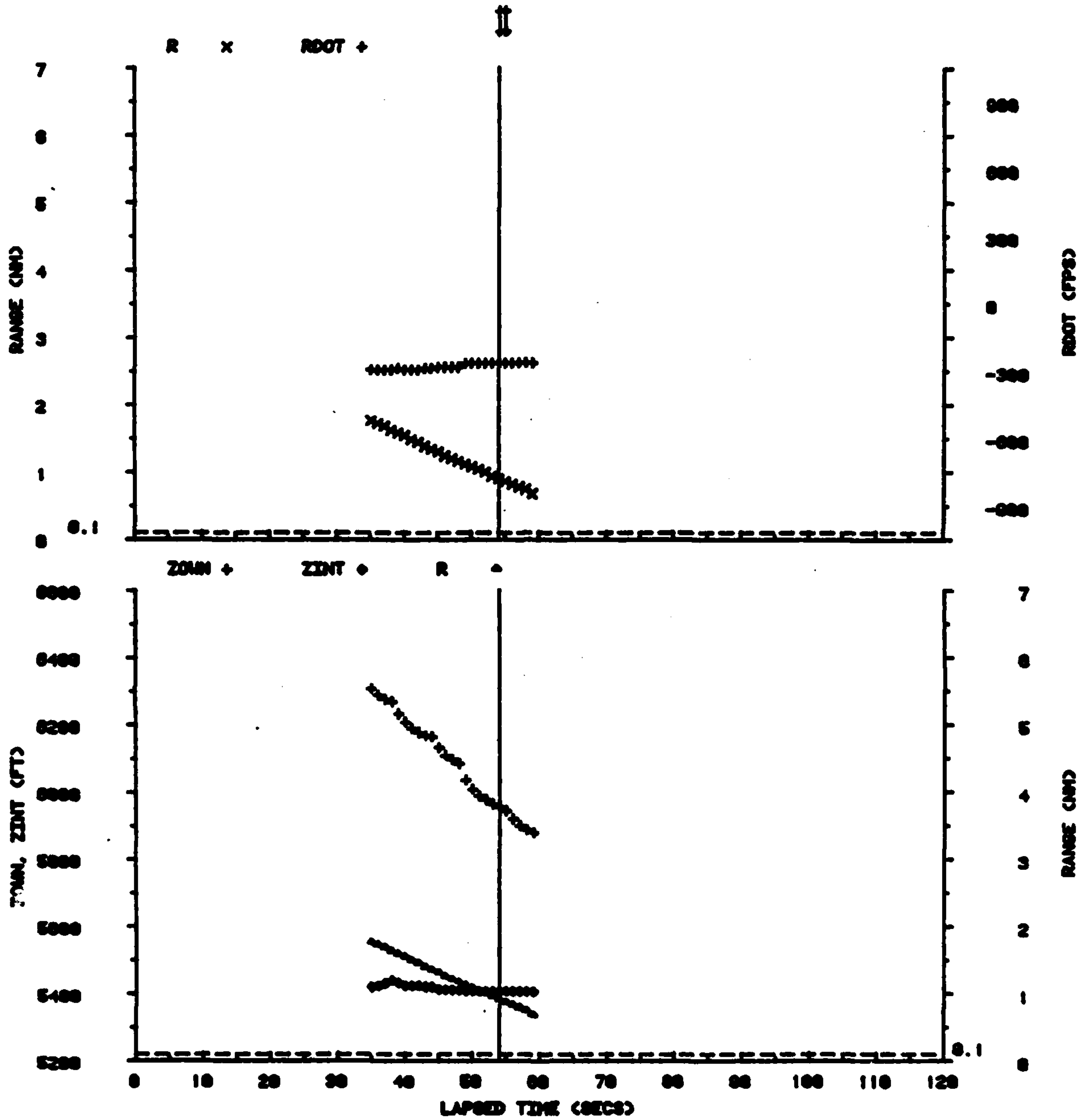


TAUR x
TAUV ◆
TAUR, TAUV (SEC)
LAPSED TIME (SECS)
18



7
5
3
1
1
3
5
7

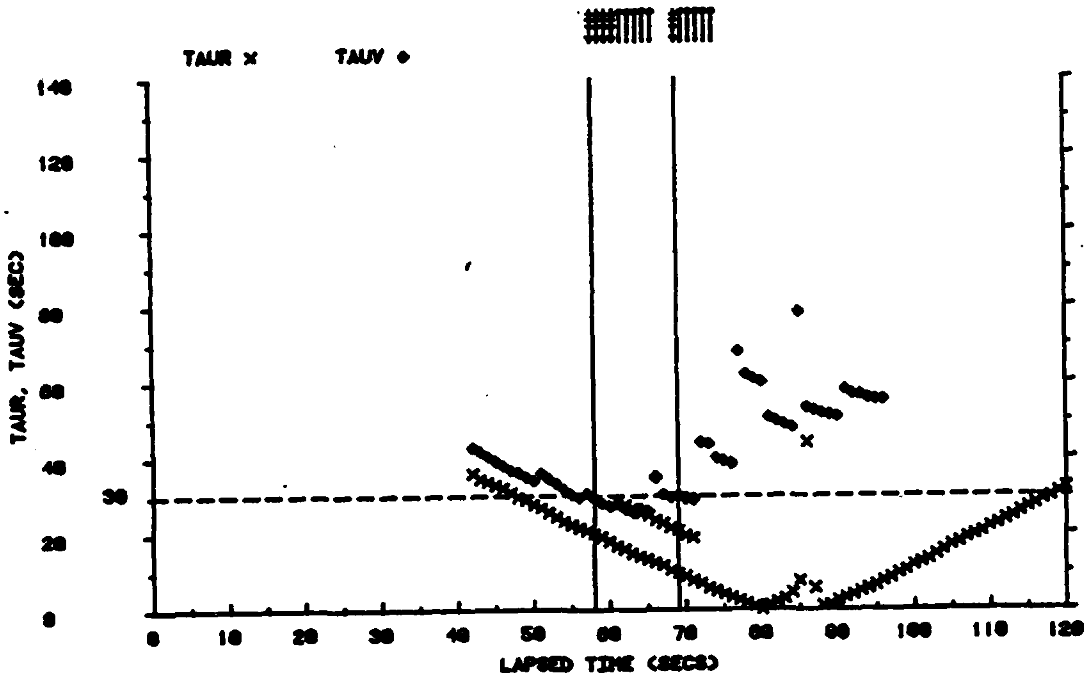

A
VHD
A, VHD (FT)
700
600
500
400
340
300
200
100
0
ZDOWN×
ZDINT◆
ZDOWN, ZDINT (FPS)
20
10
0
-10
-20
-30
-40
-50
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)


R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.1
ZOWN +
ZINT ◆
R
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

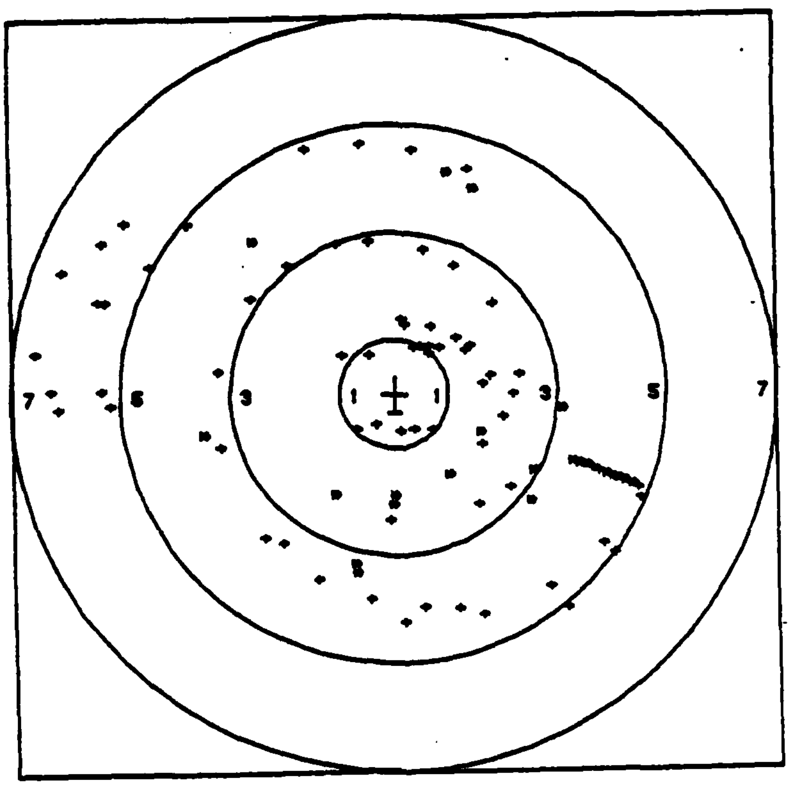
CASE 31

(Tape B064, Intruders 31/30) Suspected Double Track with Limit Descent Transitioning to Climb Advisory on Single Level Intruder Below Own Aircraft

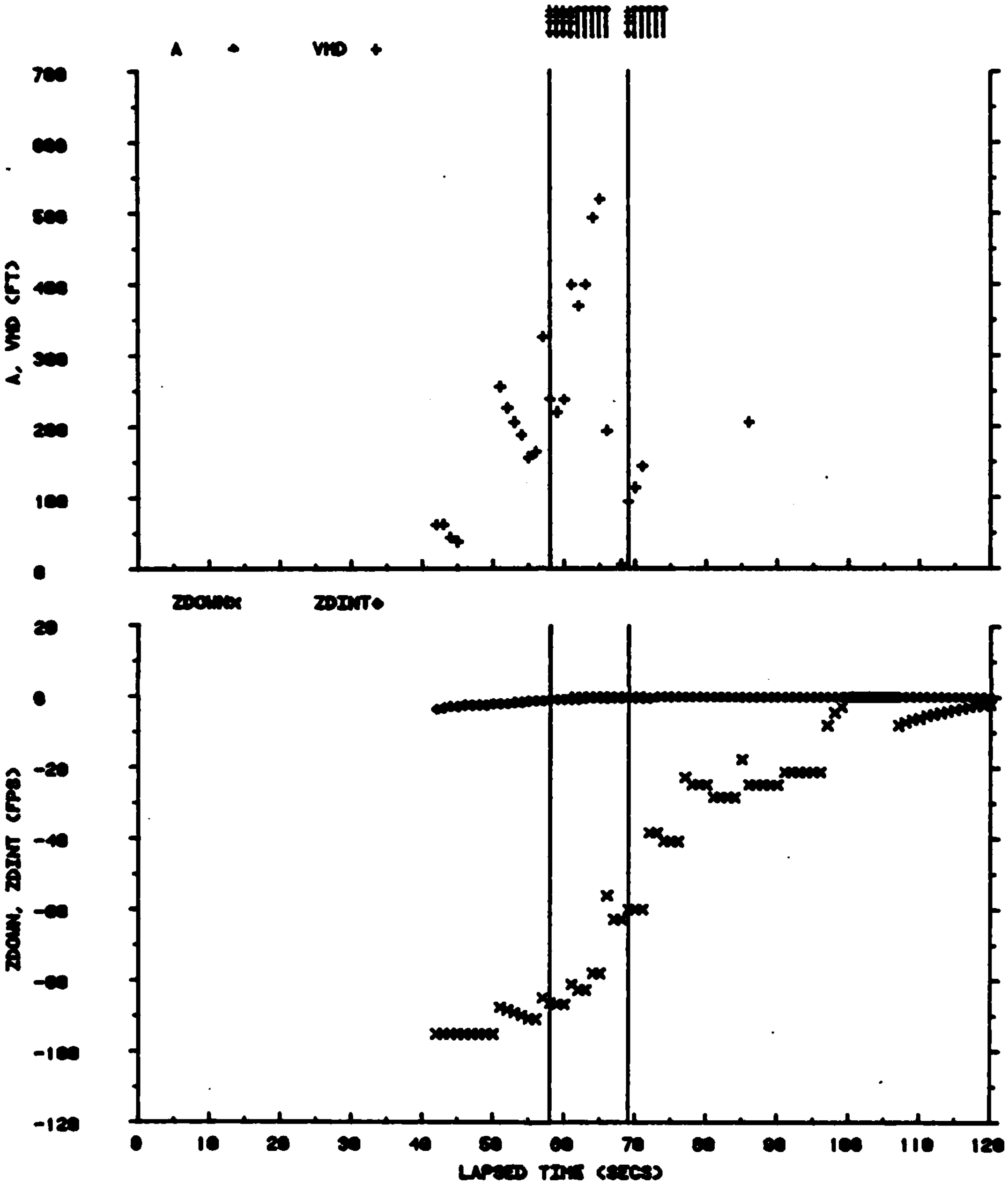
This encounter appears to show two tacks generated on the same intruder. Both tracks have the same altitude and vertical rates, and both have the same range and range rate, separated by 7 seconds. The second track started at 11000 feet and continued for 11 seconds. The advisory sequence was the same for both tracks however the LIMIT DESCENT advisories changed to a CLIMB advisory more quickly in the second case because of the smaller altitude differential.

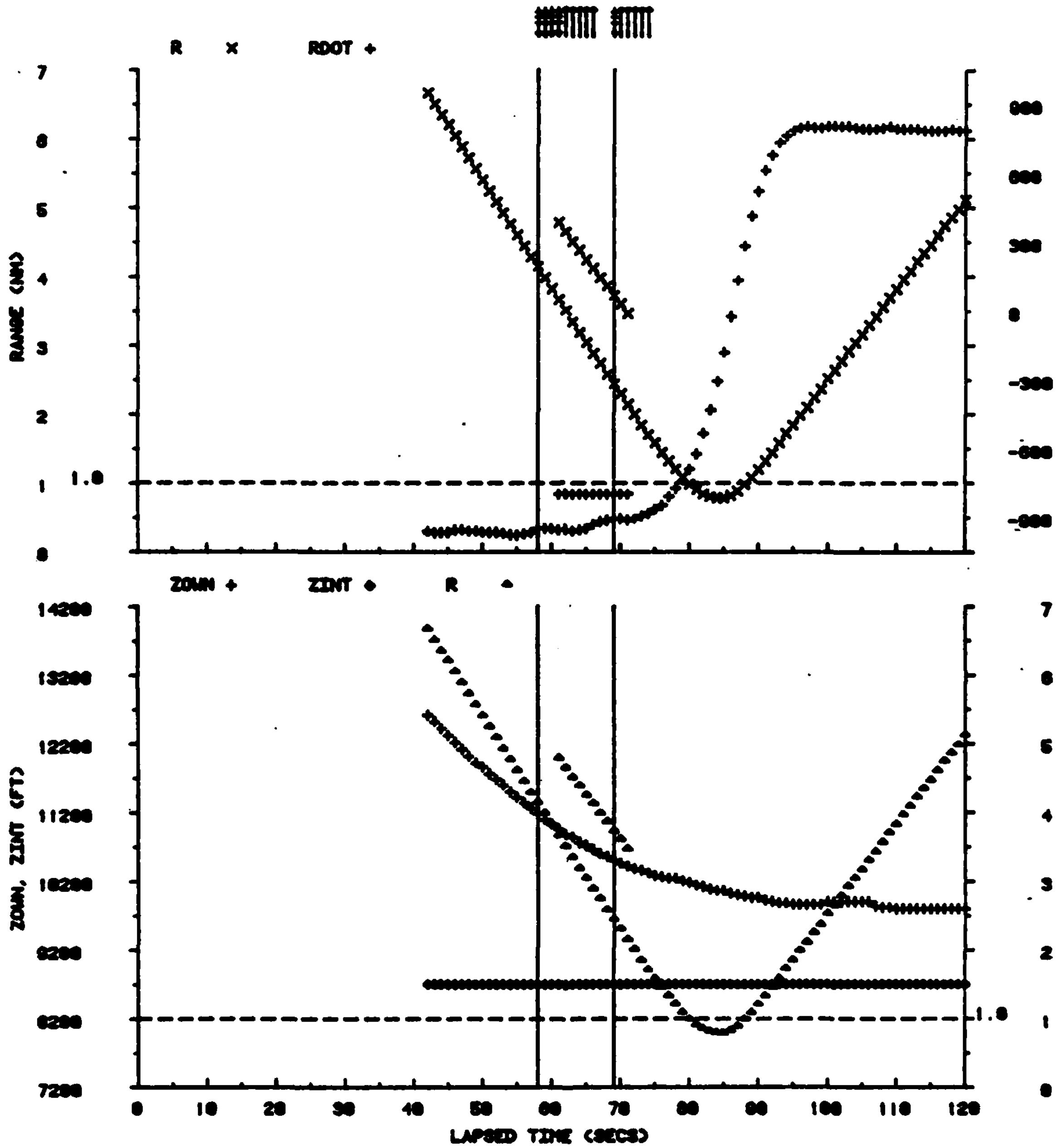


TAUR ×
TAUV ◆
140
120
100
80
60
40
30
20
0
TAUR, TAUV (SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
1
1
3
5
7


A
VMD
700
600
500
400
300
200
100
0
A, VMD (FT)
ZDOWN
ZDINT
20
0
-20
-40
-60
-80
-100
-120
ZDOWN, ZDINT (FPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



R ×
RDOT +
RANGE (NM)
RDOT (FPS)
1.0
ZOWN +
ZINT ◆
R ▲
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

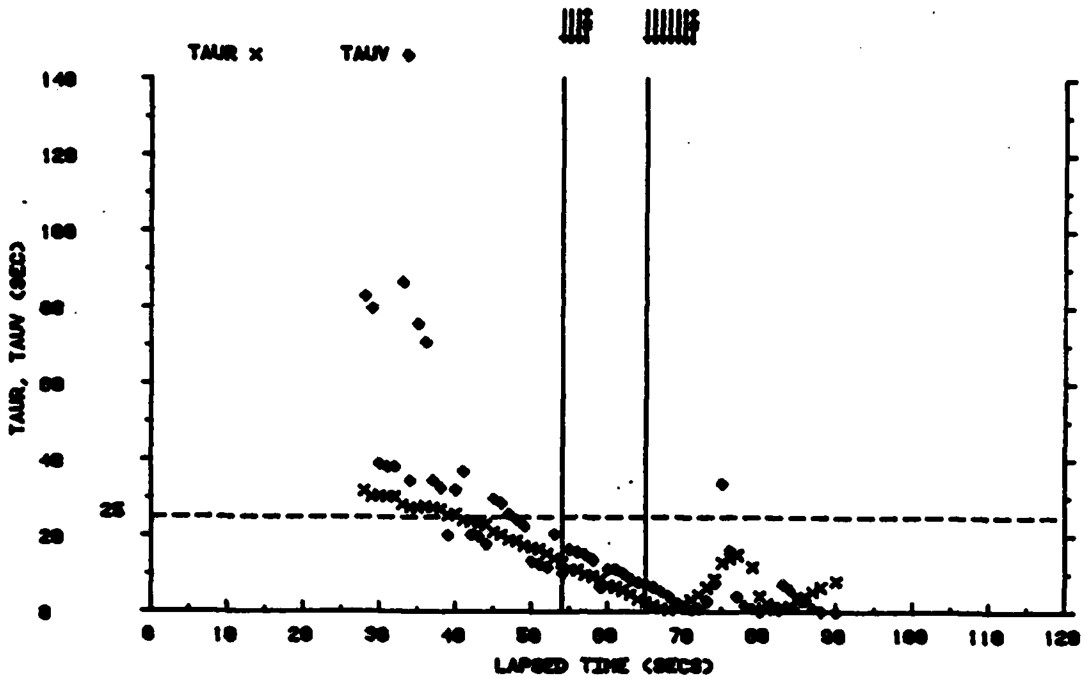
CASE 32

(Tape B064, Intruder 75) Intermittent Altitude Trip Failure Leading to Resolution Advisories on Ground Level Intruder During Appraoch to Tri-City Airport, Tennessee

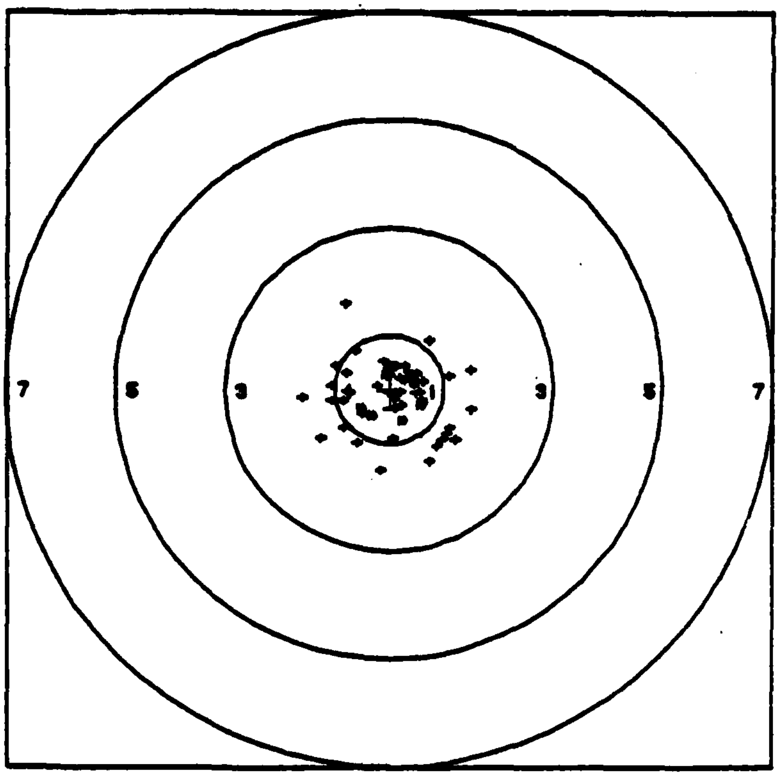
Early on the morning of March 26, 1982 Piedmont Flight 609 was on approach to Tri-City Airport, Tennessee. While on final approach, TCAS cycled into performance levels 4 and 5 with Flight 609 between 100 and 400 feet above the field elevation of 1500 feet. The surrounding terrain cannot account for the recorded behavior. Twice with own aircraft less than 500 above touchdown and the processor in the wrong performance level, an advisory sequence was initiated.

On final approach range and vertical TAU, projected vertical miss distance, and altitude separation met criteria for threat declaration. Twice with the processor cycled out of performance level 2 and resolution advisories not inhibited, unnecessary and dangerous positive Descend advisory was displayed. Without proper interface or radar altimeter difficulties leading to improper performance level selection, the logic low altitude check did not inhibit a Descend advisory. In both instances the processor cycled from performance level 5 where the positive Descend advisory was given, through performance level 4 for one second where advisory changes to a negative Don't Climb, and finally to the performance level 2 where resolution advisories are inhibited and the display was cleared.

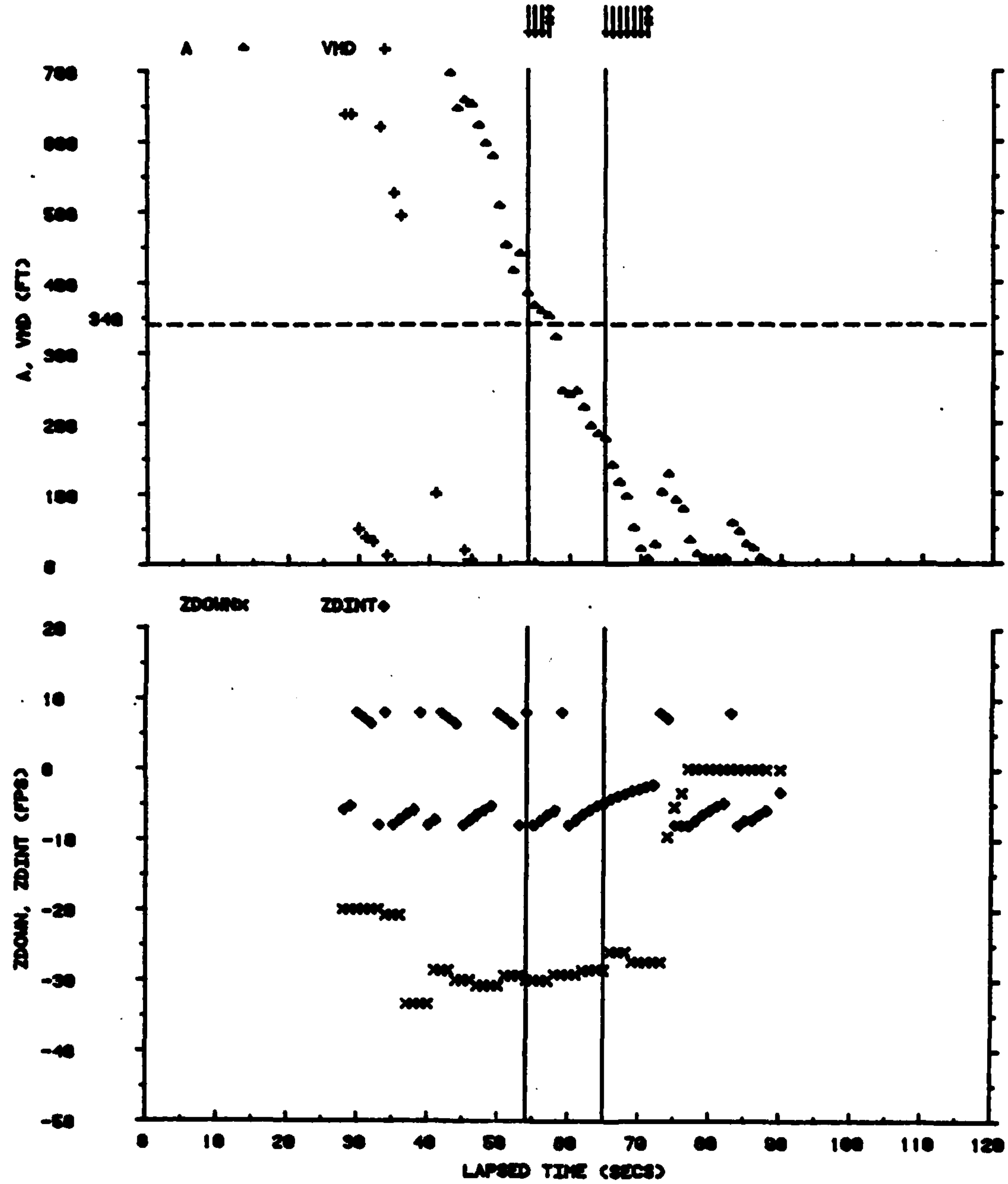
Subsequent investigation of the radar altimeter and aircraft installation failed to locate a cause for the shift in performance level. The altitude as recorded by the processor was correct. This malfunction has been referred to the equipment manufacturer.



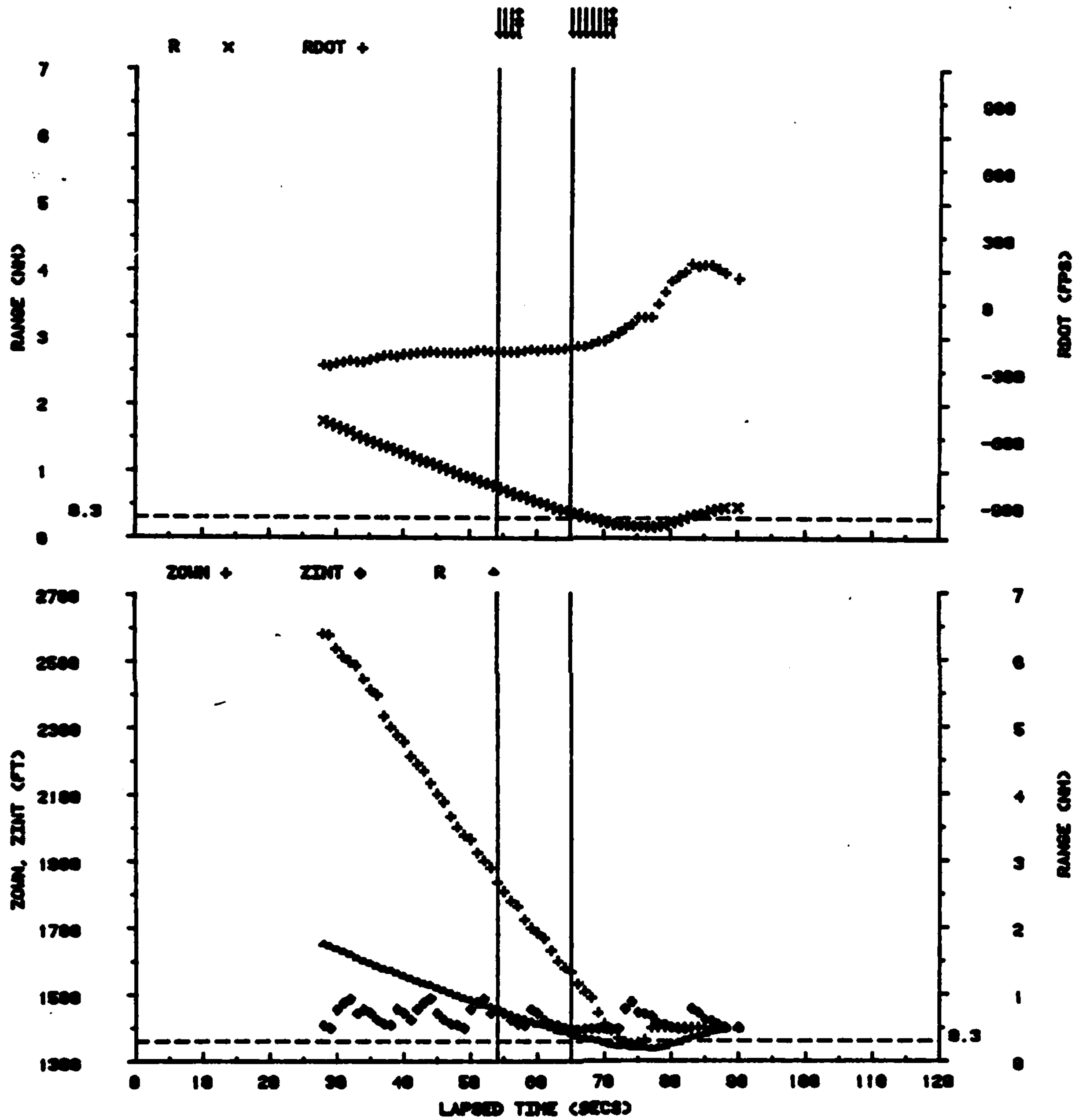
TAUR ×
TAUV ◆
TAUR, TAUV (SEC)
140
120
100
80
60
40
25
20
0
0
10
20
30
40
50
60
70
80
90
100
110
120
LAPSED TIME (SECS)



7
5
3
1
3
5
7



A
VHD
A, VHD (FT)
340
ZDOWN
ZDINT
ZDOWN, ZDINT (FPS)
LAPSED TIME (SECS)


R ×
RDOT +
RANGE (NM)
RDOT (FPS)
0.3
ZOWN +
ZINT ◆
R ◆
ZOWN, ZINT (FT)
RANGE (NM)
LAPSED TIME (SECS)

APPENDIX C

EXAMPLES OF TRAFFIC ADVISORY CASES

The following examples represent a selection of traffic advisory scenarios where a resolution advisory was not displayed. The events portrayed are as they took place. While not necessarily representative of frequent occurrences, these cases indicate issues for consideration and further evaluation. In a subsequent phase of flight test, flight crews will be able to monitor TCAS displays. TCAS in effect will always have an observer. A more definitive evaluation of traffic displays will be possible at that time.

The evaluation of the utility of the traffic advisory was made at the time of the incident by the observer.

EXAMPLE ONE

MOMENTARY TRAFFIC ADVISORY, DEPARTING DENVER
25 MARCH 1982

On March 23, 1982, an ARINC Research observer and an FAA observer were aboard Piedmont Flight 618 from Denver to Louisville. At about 1:13 p.m. local time, Flight 618 was cleared to takeoff and turn right on departure behind a heavy, a Boeing B747. With the 747 in sight in unrestricted visibility, Flight 618 lifted off and commenced a gentle right turn. Flight 618 did not tighten its turn until gaining a little altitude, and although comfortably separated, Flight 618 appeared to momentarily be on a rendezvous course with the gently turning 747. At this point, a traffic advisory was momentarily displayed on the TCAS CRT. The indication cleared when Flight 618 tightened its turn and continued its climb out.

Because of operational intent, the traffic advisory was unnecessary. It may have created a disturbance had there been any difficulty discerning the aircraft causing the alert from other proximate aircraft. Under the circumstances, it would be easy to associate the advisory with the traffic, provided the advisory was up an adequate amount of time to be caught and evaluated by a crew with its eyes initially outside the cockpit. Busy times such as these may call for a little crew coordination in the event of an advisory. Presumably the flying pilot would call the non-flying pilot or flight engineer inside the cockpit to check a traffic advisory. The potential for such a situation and advisory will always exist with the TCAS as implemented in this evaluation.

EXAMPLE TWO

TRAFFIC ADVISORIES ENROUTE, NORFOLK
20 FEBRUARY 1982

An ARINC Research observer and an FAA ATC observer were aboard Piedmont Flight 50 from Washington National Airport to Norfolk, Virginia. At 9:15 EST, four minutes after takeoff from Runway 36, Flight 50 was completing a climbing turn to the south and approaching a filed cruise altitude of 11,000 feet MSL. Washington Center was handling two other proximate aircraft and instructed Flight 50 to descend to 10,000 feet. At the same time, the TCAS aural tone alerted observers to a target displayed at 3 o'clock, 1,100 feet below own aircraft. Momentarily a second target appeared on the TCAS CRT at 2:30 to 3 o'clock at about three miles, 500 feet above own aircraft. Traffic identified as an Eastern flight was called by ATC at 3 o'clock with no altitude given. Relative altitude of higher traffic had increased to 1,100 feet above own aircraft when Flight 50 was cleared again to climb and turn direct Brooke. This turn caused the target to track outbound at 5 o'clock. From ATC it was unclear that there were two proximate aircraft. ATC later apologized for some confusion and resulting inconvenience.

Both observers were of the opinion that use of PWI displayed information could have clarified the situation and served as a valuable backup to ATC.

EXAMPLE THREE

TRAFFIC ADVISORIES IN HOLDING SOUTHEAST OF CHICAGO, 28 NOVEMBER 1982

On the evening of November 28, 1981, an ARINC Research observer was aboard Piedmont Flight 52 enroute from Richmond, Virginia, to Chicago's O'Hare Airport. Instrument conditions created by a major snow storm prevailed throughout the midwest. Chicago had a low ceiling, poor visibility, and falling snow. Missed approaches and delays forced several aircraft into holding patterns southeast of Chicago on the 120° radial between 20 and 26 DME at Plant. At approximately 5 p.m. local time, Flight 52 was instructed to hold at Plant at 10,000 feet. Flight 52 was in the clouds with falling snow. ATC was instructing other flights to hold at Plant at 1,000-foot intervals both above and below Flight 52. Multiple and sometimes simultaneous traffic advisories were displayed on the TCAS CRT. Advisories on aircraft entering and turning in holding were indicated at 7 o'clock, 1 mile, 1,900 feet below to 5 o'clock, 3 miles, 1,500 feet below; at 1 o'clock tracking to 5 o'clock, 3 to 8 miles, 1,900 feet below; momentarily at 8 o'clock, 5 miles, 900 feet below; at 11 o'clock to 1 o'clock, 5 to 2 miles, 1,000 feet above; at 2 o'clock to 5 o'clock, 5 to 4 miles, 900 feet below, etc., etc.

While it is useful to display closely proximate traffic, the aural tone sounded so frequently as to be annoying and a potential distraction in this controlled situation. Certainly it is a useful backup to show aircraft meeting potential threat criteria. It may be useful to provide pilots an option to manually select and monitor the display of all proximate aircraft. An aural tone or advisory could be reserved for smaller-than-normal threshold values or resolution advisories.

EXAMPLE FOUR

TRAFFIC ADVISORY ON TRAFFIC APPROACHING PARALLEY RUNWAY AT TAMPA, FLORIDA, 14 DECEMBER 1981

On December 14, 1981, an ARINC Research observer and an observer representing the Airline Pilot's Association were riding jumpseat aboard Piedmont Flight 53 from Charlotte, North Carolina, to Tampa, Florida. At 1:43 EST, Flight 53 was cleared north of Tampa to descend to 2,000 feet for a straight-in visual approach to Runway 18R. Approach Control called traffic at 12 o'clock, 3 miles, with no altitude report. No TCAS indication was given and the unsighted traffic was assumed to be a non-Mode-C aircraft. At 1:48 EST, Flight 53 was cleared to land on Runway 18R. Flight 53 was informed that it would be overtaking a Cessna turning on final to Runway 18L. Shortly thereafter a traffic advisory on the TCAS CRT indicated traffic at 11 o'clock less than 2 miles, and 900 feet below own aircraft. TCAS held track on the now-sighted Cessna as Flight 53 overtook and descended past the slower aircraft.

The pilot observer assessed the value of the PWI as excellent in this situation. Simultaneous approaches to parallel runways are a common occurrence. Aircraft necessarily fly close to one another and may fly at one another with intent to turn to final approach heading. In such a turn, an aircraft may be "belly-up" to traffic and have difficulty acquiring or maintaining visual contact. The pilot of an aircraft being overtaken may sometimes have difficulty sighting the approaching traffic. Such operations persist and while resolution of potential conflict situations is unnecessary, backup information on traffic of greatest concern could provide an additional safeguard.

APPENDIX D

DATA RECORDING BLOCK WORD DESCRIPTIONS

This appendix describes each word in each data block used in the data analysis.

BLOCK 0

Title: Data Loss

Description: This is recorded by the real time data recording software itself whenever data blocks are lost due to insufficient buffer space or recording capability. This block is recorded at the point where the missing blocks would have appeared.

Word	Description
1	Block number = 0
2	Word count = 4
3	System time. LSB 10msec.
4	Number of lost data blocks.

BLOCK 1

Title: Beginning of Scan (VERSION 8)

Description: This records the own-aircraft status table at the beginning of each scan. Recording is performed by the CAS subsystem (note change from earlier versions) when it performs its beginning-of-scan initialization.

Word	Description
1	Block number = 1
2	Word count = 36
3	System time. LSB=10 msec.
4	Own smoothed altitude. $\pm$ 204800 ft. LSB 100/16 ft.
5	Own altitude rate. $\pm$ 400 ft/sec., LSB $400/2^{15}$ ft/sec.
6-7	Current system time. LSB 10 msec. This is the full 32 bit system time and can be used to remove the MSB ambiguity of the 16 bit system times recorded as word 3 of each block.
8	Current scan number. First scan is scan 0.
9	Current sensitivity level specified by ATARS or ERBX. Values 0-7.
10	Number of seconds until current sensitivity level (word 9) times out. Values 0-16.
11	Last sensitivity level specified by pilot. Values 1-5.
12-13	ERBX's DABS ID, right justified with leading zeroes.
14	ERBX in track flag. 0 = No ERBX, 1 = ERBX in track.
15	2 way range to ERBX. LSB = 2us.
16	Number of unsuccessful interrogation attempts remaining before the ERBX track will be dropped. Values 0-6.
17	Number of scans until the next ERBX interrogation attempt. Values 0-4.
18-19	Own aircraft's DABS ID code, right adjusted with leading zeroes. Note that this must match the actual transponder's ID code for the ERBX function to work.
20-21	The system time when the next scan will begin. LSB 10 msec.
22-23	The system time at which this scan began. LSB 10 msec.
24	Current idle count. This counter is incremented by the system idle loop whenever no other processing is being performed. It is sampled by the real time clock interrupt handler once each second and zeroed. It increments once for each millisecond of idle time.
25	The last second's idle count sample. Dividing by 1000 gives the fraction of time the CPU was idle during that second.
26	Minimum of idle count samples since system initialization. This shows the highest CPU utilization that occurred since startup.
27	Gray code altitude read from own aircraft altimeter.
28	ATCRBS Transponder ID (Bits 3-15) and maximum airspeed capability (Bits 0-2).

BLOCK 1 (continued)

Word	Description
29	Radar altimeter input: Bit 15 (LSB): 0 = not using radar altimeter 1 = using the altimeter. Bit 0 (MSB) 0 = Below radar altimeter threshold. 1 = Above radar altimeter threshold.
30	Current CAS performance level. Values 0-7. Computed in TROACT.
31	Bit 0 (MSB): CAS INTMODE flag. 0 = BCAS may not interrogate 1 = BCAS may interrogate Bit 1: CAS INITFLAG flag 0 = CAS own aircraft altitude tracking has been initialized. 1 = CAS must initialize own altitude tracking. (First CAS cycle since system initialization). Bit 2: CAS RAMODE flag 0 = BCAS may not display its resolution advisories. 1 = BCAS may display its resolution advisories. Bit 3: CAS OPFLG flag 0 = BCAS not operational (failure of self-test). 1 = BCAS capable of full operation. Bits 4-7: CAS variable OSITID, own ATARS site ID's. Bit 4 is for site A, Bit 7 is for site D. Bits 8-15 (LSB): CAS LAYER variable. Index for table of ALIM, ZTHR, ADIV constants. Value 1-4.
32	Current year from time of day clock. Binary values 0-99.
33	Current day from time of day clock. Bits 0-7: Month, binary values 1-12. Bits 8-15: Day, binary values 1-31.
34	Current hour from time of day clock. Binary values 0-23.
35	Current second from time of day clock. Binary values 0-3599.
36	CAS input ZDONBRD. Measurement of own aircraft's vertical rate. Not available currently, and set to zero.

BLOCK 2

Title: Error Counts

Description: This records the error count array. These counters keep track of the number of times that various error conditions or other unusual events occur. They are set to zero at system initialization or restart. This block is recorded at the same time as block #1.

Word	Description
1	Block number = 2
2	Word count = 53
3	System time. LSB 10 msec.
4-53	The 50 error counts kept by the real time software, as shown below:

Word	Error	Program	Description
4	0	INIT	System initialization count. Incremented whenever the system is initializated or re-initialized. Set to zero at system load time and during power-on restart. A value of 1 is normally observed.
5	1	EXTT	The extended track file was not empty at entry to EXTT. It should have been merged to the old track file on the previous scan. Possible cause: insufficient time to process all tracks last scan. System is reinitialized.
6	2	EXTT	Load shedding. An established track was deleted and the resulting free track used to extend a closer range track.
7*	3	EXTT	An established track was deleted due to low confidence. (Number of hits vs. number of interrogations).
8	4	MRGE	An established track was merged with another track.
9	5	EXTT	An established track was deleted when the number of consecutive coasts became greater than the allowed maximum.
10	6	EXTT	An established track was deleted when its predicted position fell outside the threat volume.
11	7	GETTN (VERSION 8)	No free surveillance file number available for ARCRBS or DABS.

*Not used.

BLOCK 2 (continued)

Word	Error	Program	Description
12	8	-	Unused
13	9	-	Unused
14*	10	DBSOS	At start-of-scan either there was no DABS track in squitter state with own aircraft's ID, or the altitude of that track was not in reasonable agreement with own aircraft's altitude as determined by the BEU. Indicates either DABS transponder failure, altitude distribution failure, or that own DABS ID is incorrectly set in the own-aircraft status record OWNAC (see data block #1).
15	11	DBSOS	A track on the squitter/dormant list did not have squitter/dormant status. The track is deleted from the list.
16	12	DBSOS	A track on the acquisition/rollcall list was not in acquisition/rollcall state. The track is deleted from the list.
17	13	DABS	The DABS interrogation buffer (beginning at location DIBUF) did not have either start-of-scan or interrogation-complete status when the DABS task was awakened. The DABS task goes back to sleep.
18	14	SQUIT	No empty track record available to start a squitter track.
19	15	DBSOS	Some acquisition or rollcall track did not get to complete its allotted interrogations before the end of the scan.

(Note: The following definitions of errors 16-25 apply only to Version 8 and later of the BEU software.)

Word	Error	Program	Description
20	16	CUPDATE	Intruder surveillance buffer overflowed when ATCRBS or DABS attempted to add a target report.
21	17	TRIACT	No free CAS track file records available.
22	18	TRFONEW	No free CAS threat file records available.
23	19	TRAFCOR TRAFDET	No CAS traffic advisory file entries available.

*Not used

BLOCK 2 (continued)

Word	Error	Program	Description
24	20	-	Not used.
25	21	RARREQ	RAR as received by CASINT contains a column with an invalid vertical or horizontal field. The invalid field is set to zero.
26	22	RMAP	A vertical or horizontal field of a column of the internal RAR contains an unexpected value. The corresponding column in the external RAR (ERAB) is zero.
27	23	-	Not used.
28	24	TRFOUPD	Invalid threat file pointer when trying to update or delete a threat file entry. TRFOUPD exits without taking any action.
29	25	CAS	CAS was awakened, but not due to start-of-scan. CAS goes back to sleep.
30	26	CAS	CAS was not awakened for one or more scans. Processing continues normally.
31	27	-	Not used.
32	28	-	Not used.
33	29	-	Not used.
34	30	IGPIO	Squitter reply buffer overflow. Squitter listening is temporarily disabled until buffer space is available.
35	31	IGPIO	The current hardware reply buffer was filled and an end-of-transfer interrupt generated. This error is only incremented while listening for DABS or ATCRBS replies. This condition is normal for squitter listening, where the buffer is used as a circular buffer, and therefore the error count is not incremented in that case.
36	32	BUFCK	The hardware transfer address at termination of input was past the end of the input buffer. The system is reinitialized.
37	33	BUFCK	The hardware transfer address is termination of input was less than its initial value at the start of I/O. The system is reinitialized.

BLOCK 2 (continued)

Word	Error	Program	Description
38	34	ICLK	The "last mode" flag LUCU did not indicate squitter listening mode at a time when ICLE was ready to send an interrogation. The system is reinitialized.
39	35	TROACT (through Version 7) ICLK (Version 8)	The measured altitude for own aircraft has invalid C bits. Own altitude is coasted.
40*	36	IQTI	CRC or START error bit set on cartridge tape status. Write operation will be retried after a timeout.
41*	37	IQTI	Status received upon issuing a write command, rather than after the following data transfer for the write operation. The write operation is aborted on the assumption that the drive is not ready for a write operation. It will be retried after a timeout.
42*	38	DREC	Timeout occured on a cartridge write operation. Write operation restarted.
	39	TROACT (through Version 7)	The own aircraft altitude rate correction was too large. Altitude is updated, but the rate is not. Indicates faulty own aircraft altimeter operation.
43	39	(Version 8)	Not used.
44*	40	INIT	The system idle loop counted for two seconds without being cleared by the real time clock interrupt. Probable cause is failure of the real time clock. The system is reinitialized.
	41	CIRUPD (through Version 7)	Could not update CIR due to an SMI active status.
45	41	(Version 8)	Not used.
	42	CIRUPD (through Version 7)	Could not update CIR, as could not lock CIR in own BCAS.

*Not used.

BLOCK 2 (continued)

Word	Error	Program	Description
46	42	(Verison 8)	Not used.
47*	43	IGPIO	Data read back from the CIR or RAR board does not match that output to it.
48	44	RCV	DABS transponder input message queue overflow.
49	45	ICLK	When sampled at the end of one second the idle count was zero. System reinitialized.
50*	46	IVECT	Illegal instruction trap. The system is re-initialized. Octal location 42 in memory will contain the address of the illegal instruction. The software stores illegal instructions throughout upper core in order to detect wild jumps.
51*	47	IVECT	Stack overflow trap. The system is reinitialized. Octal location 44 in memory will contain the address of the instruction following the PUSH instruction that caused the trap.
52*	48	IVECT	An interrupt was received from an unexpected device (i.e., whose device code is unknown to the system). An attempt is made to clear the device.
53*	49	IVECT	At entry to the power-on restart program, the hardware IBN flag was not cleared. This indicates that the power-on restart program was entered due to a jump to location zero by some program, rather than by a power-on condition. The system is re-initialized.

*Not used.

BLOCK 10

Title: CAS Intruder Track File Record (VERSION 8)

Description: The entire set of active CAS intruder track file records is recorded at the end of the CAS cycle. One such track record is recorded in each block 10, and so typically several block 10 recordings will appear together on the data tape. Names in parentheses are those used in the CAS logic description to reference these variables.

Word (bits)	Description
1	Block number = 10
2	Word count = 28
3	System time. LSB 10msec.
4-5	Link field linking this track to the intruder track file.
6-7	Link field linking this track to the working list.
8	Tracked range (R) 0-64 nm, LSB 1/1024 nm.
9	Tracked range rate (RD)$\pm$3600 KT, LSB $1/2^{15}$ nm/sec.
10	Tracked bearing, measured from the nose, clockwise, looking down (right wing is 90°). $0\text{-}360°/2^{16}$.
11	Tracked bearing rate. $\pm$180°/sec, LSB $360°/2^{16}$ deg/sec. Note: This differs from the units recorded by Dalmo Victor for this field.
12	Time of last data report (TREPT), least significant 16 bits of system time. LSB 10 msec.
13	Tracked relative altitude (RZ)$\pm$204800 ft, LSB 100/16 ft. Positive values indicate that the intruder is below own aircraft.
14	Tracked relative altitude rate (RZD)$\pm$400 ft/sec, LSB $400/2^{15}$ ft/sec. Positive values indicate that RZ (word 13) is increasing.
15(0-7)	Surveillance track number.
15(8-15),16	DABS ID of intruder (IDINT). Set to zero if intruder is not DABS equipped.
17	Absolute value of relative altitude (A). 0-204800 ft, LSB 100/16 feet.
18	Relative altitude rate (ADOT).$\pm$400 ft/sec. LSB $400/2^{15}$ ft/sec. Positive indicates that the intruder is separating in altitude.
19	Pointer to the record for the intruder in the threat file, if any. Null if no threat file entry exists.
20(0-2)	Equippage of intruder (EQ): 0 : ATCRBS 1 : DABS 2 : ATARS 3 : BCAS enabled 4 : BCAS inhibited
20(3-4)	Working list status (STATUS): 0 : No status 1 : New 2 : Continue 3 : Terminate
20(5-7)	Sensitivity level of intruder (PLINT). Values 0-7
20(8-11)	ATARS site ID's for intruder (ISITID). Bit 8 (MSE) = Site A Bit 11 (LSB) = Site D.

BLOCK 10 (continued)

Word (bits)	Description (continued)
20(12)	Don't care flag (DCFLAG). Set to 1 if there is no substantial preference for choosing climb or descend sense against this intruder.
20(13-15)	Hit counter (KHIT).
21	Time to closest approach (TRTRU). 0-655.35 sec, LSB 0.01 sec.
22	Expected vertical miss distance (VMD). ±204800 ft, LSB 100/16 ft.
23	Pointer to the appropriate CAS logic parameter table.
24-25	CAS trace bit vector. The bits set indicate which path was followed through the CAS logic for this intruder on this CAS cycle.

Bit	Program where set, meaning if set
0 (MSB)	TRIACT, track is coasted
1	DETECT, BRESP = 0
2	DETECT, BRESP = 1
3	HITORM, range criteria met
4	HITORM, hit declared
5	RESCOOR, status=terminate
6	RESCOOR, status = new
7	RARREQ, no RAR reply received
8	TRFONEW, intruder has threat file record
9	MODAC, advisory not effective, project at current rates.
10	MODAC, no previous advisory, model climb and descend
11	MODAC, no previous advisory, altitude rates to small
12	MODAC, previous negative advisory
13	MODAC, previous positive advisory
14	SELSEN, initial choice of sense is descend
15	SELSEN, second choice acceptable, DCFLAG = 0.
16	SELSEN, MTOW = 1 or MTTH = 0
17	SELSEN, compatible
18	SELADV, positive vertical selected
19	SELADV, negative vertical not selected
20	SELADV, VSL test inappropriate
21	SELADV, negative VSL test selected
22	SELADV, negative vertical selected
23	TRFMAC, all positive commands set of negative
24	TRFMAC, no change
25	TRFMAC, all negative commands to positive
26	TRAFDIS, intruder has a traffic advisory file record
27	TRAFDIS, intruder has a traffic display vector record
28	Not used.
29	Not used.
30	Not used.
31 (LSB)	Not used.

26	Tracked altitude (ZINT). ±204800 ft, LSB 100/16 ft.
27	Tracked altitude rate (ZDINT). ±400 ft/sec, LSB $400/2^{15}$ ft/sec.
28	Time of latest track update (TDATAI). Least significant 16 bits of system time. LSB 10 msec.

BLOCK 11

Title: Display Vector (VERSION 8)

Description: This records the CAS display vector at the end of the CAS cycle, as it was sent to the display generation software.

Word (bits)	Description (for single bits, meaning if set to 1)
1	Block number = 11
2	Word count = 5
3	System time. LSB 10 msec.
4(0)(MSB)	Climb
4(1)	Don't descend
4(2)	Limit descent to 500 ft/min.
4(3)	Limit descent to 1000 ft/min.
4(4)	Limit descent to 2000 ft/min.
4(5)	Descend
4(6)	Don't climb
4(7)	Limit climb to 500 ft/min.
4(8)	Limit climb to 1000 ft/min.
4(9)	Limit climb to 2000 ft/min.
4(10)	Turn left.
4(11)	Turn right.
4(12)	Don't turn left.
4(13)	Don't turn right.
4(14-15)/ (LSB)	Not used.
5(0)(MSB)	Climb faster than 500 ft/min.
5(1)	Climb faster than 1000 ft/min.
5(2)	Climb faster than 200 ft/min.
5(3)	Descend faster than 500 ft/min.
5(4)	Descend faster than 1000 ft/min.
5(5)	Descend faster than 2000 ft/min.
5(6)	BCAS operational.
5(7)	Trigger audible alarm
5(8-12)	Not used
5(13-15)/ (LSB)	Sensitivity level.

BLOCK 12

Title: Encoded RAR (VERSION 8)

Description: This records the state of the RAR at the end of the CAS cycle. Although this does not record each change to the RAR that might occur during the cycle, it is felt to be sufficient for determining the system's behavior given that inputs from the DABS transponder interface are also recorded (block 14).

Word (bits)	Description
1	Block number = 12
2	Word count = 7
3	System time. LSB 10msec.
4	Downlink data inserted by BCAS via SMI.
5(0-2)	HO1. Horizontal advisories from ATARS site A.
5(3-7)	VE1. Vertical advisories from ATARS site A.
5(8-10)	HO2. Horizontal advisories from ATARS site B.
5(11-15)	VE2. Vertical advisories from ATARS site B.
6(0-2)	HO3. Horizontal advisories from ATARS site C.
6(3-7)	VE3. Vertical advisories from ATARS site C.
6(8-10)	HO4. Horizontal advisories from ATARS site D.
6(11-15)	VE4. Vertical advisories from ATARS site D.
7(0-2)	HO5. Horizontal advisories from own BCAS.
7(3-7)	VE5. Vertical advisories from own BCAS.
7(8-10)	HO6. Horizontal advisories from all other BCAS.
7(11-15)	VE6. Vertical advisories from all other BCAS.

The coding for the horizontal advisory fields is as follows:

Value	Meaning
0	No horizontal advisories
1	Not assigned
2	Turn left
3	Turn right
4	Don't turn left
5	Don't turn right
6	Not assigned
7	Don't turn left and don't turn right

The coding for the vertical advisory fields is as follows:

Value	Meaning
0	No vertical advisories
1-3	Not assigned
4	Don't descend
5	Don't descend faster than 500 fpm.
6	Don't descend faster than 1000 fpm.
7	Don't descend faster than 2000 fpm.
8	Don't climb.
9	Don't climb faster than 500 fpm.
10	Don't climb faster than 1000 fpm.

BLOCK 12 (continued)

Value	Meaning
11	Don't climb faster than 2000 fpm.
12	Not assigned.
13	Climb.
14	Not assigned.
15	Descend.
16	Don't descend and don't climb.
17	Don't descend and don't climb faster than 500 fpm.
18	Don't descend and don't climb faster than 1000 fpm.
19	Don't descend and don't climb faster than 2000 fpm.
20	Don't descend faster than 500 fpm and don't climb.
21	Don't descend faster than 500 fpm and don't climb faster than 500 fpm.
22	Don't descend faster than 500 fpm and don't climb faster than 1000 fpm.
23	Don't descend faster than 500 fpm and don't climb faster than 2000 fpm.
24	Don't descend faster than 1000 fpm and don't climb.
25	Don't descend faster than 1000 fpm and don't climb faster than 500 fpm.
26	Don't descend faster than 1000 fpm and don't climb faster than 1000 fpm.
27	Don't descend faster than 1000 fpm and don't climb faster than 2000 fpm.
28	Don't descend faster than 2000 fpm and don't climb.
29	Don't descend faster than 2000 fpm and don't climb faster than 500 fpm.
30	Don't descend faster than 2000 fpm and don't climb faster than 1000 fpm.
31	Don't descend faster than 2000 fpm and don't climb faster than 2000 fpm.

BLOCK 13

<u>Title:</u> Threat File Record (VERSION 8)

<u>Description:</u> Each block 13 records one entry in the CAS threat file. The entire threat file is recorded at the end of the CAS cycle by means of several block 13 records. Names in parenthesis are those used to refer to these quantities in the CAS logic description.

Word (bits)	Description
1	Block number = 13
2	Word count = 15
3	System time. LSB 10msec.
4-5	Link field to link this record to the remainder of the threat file.
6	Pointer to the intruder track file record for this threat (TFRWO)
7(0-11)	Current choice of resolution advisory with reagrd to this threat (PERMTENT).

Bit	Meaning
0 (MSB)	Horizontal advisory present, 1 = Yes, 0 = No
1	Horizontal advisory negative, 1 = Yes, 0 = No
2	Horizontal sense, 1 = Right, 0 = Left
3	Vertical advisory present, 1 = Yes, 0 = No.
4-5	Vertical advisory type 0 : Positive 1 : Positive VSL 2 : Negative 3 : Negative VSL
6	Vertical sense. 1 = descend, 0 = climb.
7-9	Unused
10-11 (LSB)	Vertical speed limit 0 : No vertical speed limit 1 : 500 ft/min 2 : 1000 ft/min 3 : 2000 ft/min

Word (bits)	Description
7(12-15)	Unused.
8(0-11)	Previous choice of resolution advisory with respcet to this threat (CMDSAV). Same bit coding as word 7(0-11), PERMTENT.
8(12-15)	Unused
9(0-7)	Index of own intent in own BCAS row of RAR (POOWRAR).
9(8-15)	Index of intruder's intent in "other BCAS" row of RAR (POTHRAR).
10	Time of last change in own advisory (TCMD). Least significant 16 bits of system time. LSB 10 msec.
11(0)	Set to 1 if coordination failed (FAIL).
11(1)	Set if intruder is in a multi-threat situation (MTTH).
11(2)	Set if own BCAS sees a multi-threat situation (MTOW).
11(3-7	Unused.
11(8-15),12	DABS ID of threat, 0 if nto DABS equipped, (TRFDABS).

BLOCK 13 (continued)

Word (bits)	Description
13	Timer for last refresh of own resolution advisory (TLRCMD). Least significant 16 bits of system time. LSB 10 msec.
14	Timer for last change in threat's resolution advisory (TTHCMD). Least significant 16 bits of system time. LSB 10 msec.
15	Timer for last refresh of threat's resolution advisory (TTHLRCM). Least significant 16 bits of system time. LSB 10 msec.

END

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